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Analysis of the Bivariate Parameter Wind Differences Between Jimsphere and Windsonde

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I. INTRODUCTION

During the Space Shuttle launches at Kennedy Space Center (KSC), Florida, the FPS-16 Radar/Jimsphere System is the standard wind sensor and the Meteorological Sounding System (MSS) Windsonde is the backup. The purpose of this report is to present an analysis of the bivariate parameter difference between the Jimsphere and Windsonde. From the 64 pairs of Jimsphere balloon releases which supported 14 Space Shuttle launches used to determine the ascent loads of the shuttle, the statistics of the mean and standard deviation of the u (zonal component), and v (meridional component), shears, and power spectral density for the Jimsphere and Windsonde are presented in Section 4. Section 2 discusses the terrestrial environment (below 20 km). The description is given of the wind environment such as the sinusoidal flow, jet stream winds, high winds (deep altitude layers), vertical wind motion, spikes, and sequential wind profiles. Section 3 describes in detail the FPS-16 Radar/Jimsphere, the Meteorological Sounding System (MSS) Windsonde, and a summary of wind error estimates of the Jimsphere and Windsonde. The statistics of the Jimsphere and Windsonde differences are given in Section 4. Section 5 presents the summary remarks. Appendices A, B, and C present a typical sequence of Jimsphere and Windsonde support for a Space Shuttle launch, STS-61B (November 26, 1985, 1829Z).

II. DISCUSSION OF TERRESTRIAL ENVIRONMENT (BELOW 20 KM)

The lowest region of the atmosphere, the troposphere, extends to an average height of about 11 km. Over the equator, the average height is about 18 km, and over the poles about 8 km.

The troposphere (a name coined by the British meteorologist, Sir Napier Shaw, from the Greek word "tropos", meaning turning) is a region of ceaseless turbulence and mixing. It is a region of rain, hail, and hurricanes (Vaughan and DeVries, 1972:74).

The source of the air we breathe and the caldron of all weather, the troposphere is the region of greatest importance to man. It contains, for example, almost all of the atmosphere's water vapor. And although the troposphere accounts for only a tiny fraction of the Earth's atmosphere's total height, it contains about 80 percent of its total mass.

In the troposphere, the temperature decreases almost linearly with height. This decrease is about 6.5°C per kilometer. The reason for this progressive decline is the increasing distance from the source of heat – the sun-warmed Earth. At the top of the troposphere, the temperature has fallen to an average of about 217°K (-55°C).

Because of the thorough mixing of the troposphere, the chemical composition of the normal, dry, uncontaminated air remains essentially unchanged with increasing altitude. Two gases, nitrogen and oxygen, account for 99.03 percent by volume (clean, dry basis) of the air. These two gases plus argon and carbon dioxide account for 99.997 percent by volume of clean, dry air. The total concentration of the numerous other gases present is thus a miniscule 0.003 percent.

The concentration of some of the minor gases such as argon, neon, and helium remains virtually constant. On the other hand, the concentration of some of the other minor gases such as ozone, sulphur dioxide, and nitrogen dioxide varies, although in most cases only slightly. The content of water vapor, however, varies enormously – from 20 grams or more per kilogram of air in the tropics to less than 0.5 gram per kilogram in the dry polar regions.

In addition to gases, the troposphere contains a wide array of solids – dust, carbon particles, salt, and bacteria. It also contains suspended liquids, the most important of which is water.

Table 1 lists the composition of clean, dry air near sea level.

2.1 Description of Environments – Natural and Induced Environment

The wind data presented in this report are focused on information below 20 km in the so-called terrestrial environment. The environment in which an aerospace system must operate consists of natural and induced forces (Hill, 1986:3). The induced environment is the environment which is a result of the system being present as indicated by Susko and Kaufman (1973a:341-345) and Susko (1979:48-56). The natural environment is the environment existing naturally and undisturbed in the presence and the absence of the system.

Induced environments (vehicle caused) may be more critical than natural environments for certain vehicle operational situations, and in some combination of natural and induced environments will be more severe than either environment alone. Thus, induced environments and natural environments must be considered in the final analysis. A review of special detailed wind profile measurements obtained from the natural environment was reported by Kaufman and Susko (1971:6489) and briefly related how vehicles respond to winds aloft by Fichtl (1972a:79) from the induced environment.

Evaluations of space vehicle response to upper altitude winds show that vehicle loads are relatively large when flown through wind profiles having (a) high-wind speed magnitudes with associated large shears or (b) low to moderate wind speed magnitudes with successive perturbations (spikes) or through wind profiles which are nearly in phase with the control or structural modes as described by Fichtl (1972b:767-770). A description of the spikes, sinusoidal waves, jet streams, high winds (thick layers), sequential wind profiles, vertical wind motion, and winds (a major forcing function) is presented.

Table 2 lists the date, time of Jimsphere release, and the site where the profiles were observed by Kaufman and Susko (1971:6489). A space vehicle's flight trajectory, size, and mode of flight through the winds aloft, among other factors, determine which wind features are of more concern. A composite of 12 FPS-16 Radar/Jimsphere balloon wind profile measurements, from Kennedy Space Center, Florida, illustrate the sequential data set of winds varying over 24 hr with time separations of 1.5 to approximately 6 hr [Susko and Kaufman (1973b:2)]. Horizontal wind speed and direction at 25 m intervals from near the surface to approximately 18 km altitude were acquired. This system allows wind measurement throughout the troposphere and lower stratosphere as reported by Vaughan (1968:41); Fichtl and McVehill (1970:79); Johnson and Vaughan (1978:3).

2.1.1 The Spikes

The distinctive feature of the spikes can be seen in Figure 1 at 12 km, 2 at 13 km, 3 at 13 km, 4 at 6 km, and 5 at 13 km [Kaufman and Susko (1971:6489)]. The spike is characterized by a sudden increase in wind speed, and then decrease in speed to some steady-state value. Such spikes may be associated with a change in wind direction, and may persist for only a short period of time (1 to 2 hr) over a very shallow altitude layer (Figs. 1a through 5a). A distinct wind direction variation is apparent for the spikes shown in Figure 2. The spikes are very difficult to forecast because their structure is quite complex and is not always well understood (Figs. 1 through 5.)

TABLE 1. COMPOSITION OF CLEAN, DRY AIR* NEAR SEA LEVEL

COMPONENT		CONTENT, PER CENT BY VOLUME	MOLECULAR WEIGHT
NITROGEN		78.084%	28.0134
OXYGEN		20.9476	31.9988
ARGON		0.934	39.948
CARBON DIOXIDE		0.0314	44.00995
NEON		0.001818	20.183
HELIUM		0.000524	4.0026
KRYPTON		0.000114	83.80
XENON		0.0000087	131.30
HYDROGEN		0.00005	2.01594
METHANE		0.0002	16.04303
NITROUS OXIDE		0.00005	44.0128
OZONE	SUMMER:	0 TO 0.000007	47.9982
	WINTER:	0 TO 0.000002	
SULFUR DIOXIDE		0 TO 0.0001	64.0628
NITROGEN DIOXIDE		0 TO 0.000002	46.0055
AMMONIA		0 TO TRACE	17.03061
CARBON MONOXIDE		0 TO TRACE	28.01055
IODINE		0 TO 0.000001	253.8088

*(CRAIG, 1965:7), (VAUGHAN AND DeVRIES, 1972:79)

TABLE 2. SUMMARY OF FPS-16 RADAR/JIMSPHERE WIND PROFILE DATA

Figures	Test	Date	Time of Release, GMT	Site
1, 1a	6255	February 22, 1966	0439	Cape Kennedy, Florida
2, 2a	2440-5	May 30, 1966	0650	Cape Kennedy, Florida
3, 3a	2838-3	April 4, 1966	1014	Cape Kennedy, Florida
4, 4a	7063-02	November 8, 1967	2103	Cape Kennedy, Florida
5, 5a	0419-03	January 21, 1968	1300	Cape Kennedy, Florida
		Sinusoidal Waves *		
6, 6a	1580-3	February 26, 1966	1300	Cape Kennedy, Florida
7, 7a	7109	November 22, 1966	0100	Cape Kennedy, Florida
8, 8a	6656-03	February 14, 1968	1300	Cape Kennedy, Florida
9, 9a	7620	November 23, 1966	1300	Cape Kennedy, Florida
10, 10a	10306-01	April 23, 1968	1630	White Sands, New Mexico
		Jet Stream Winds		
11, 11a	0055	February 22, 1966	1715	Cape Kennedy, Florida
12, 12a	0770	July 13, 1966	0130	Cape Kennedy, Florida
13, 13a	4510	December 2, 1966	0101	Cape Kennedy, Florida
14, 14a	3370-02	December 28, 1967	0100	Cape Kennedy, Florida
15, 15a	0426-03	January 31, 1968	1300	Cape Kennedy, Florida

*Peaked ocillations.

SCALAR WIND SPEED PROFILE

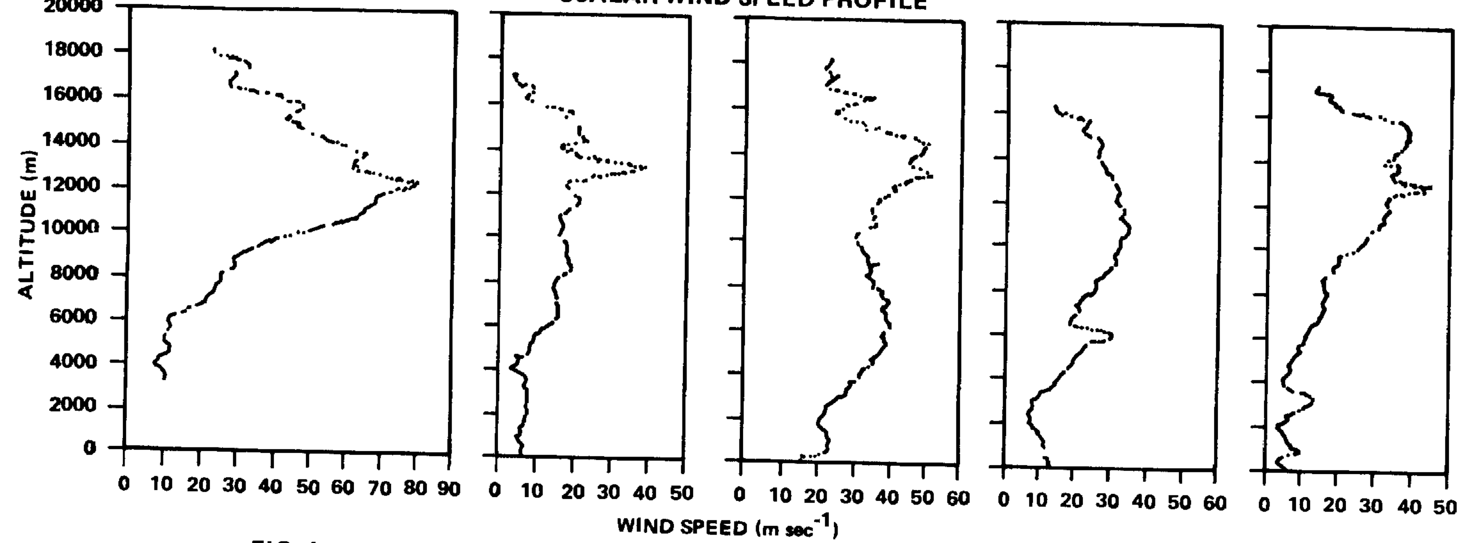


FIG. 1 FIG. 2 FIG. 3 FIG. 4 FIG. 5

WIND DIRECTION PROFILE

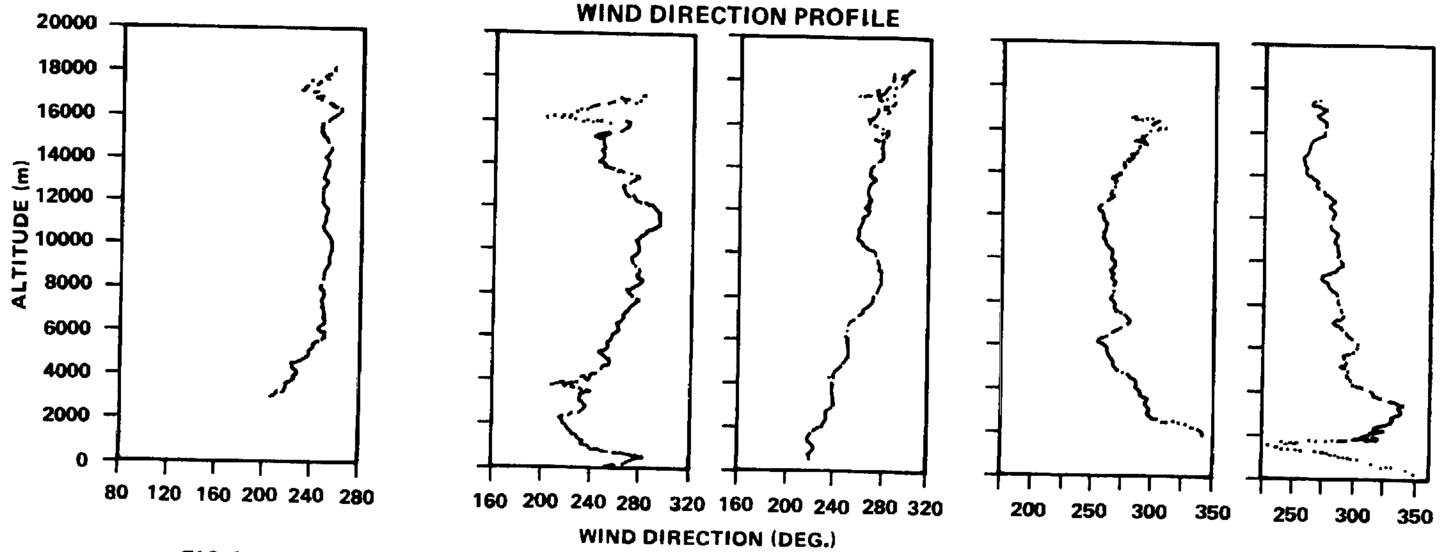


FIG.1a FIG. 2a FIG. 3a FIG. 4a FIG. 5a

Figures 1 through 5a are examples of spikes. The graphs show scalar wind speed and wind direction profiles versus altitude.

2.1.2 The Sinusoidal Waves

Regular oscillations (sinusoidal waves) can frequently be identified in wind speed and direction profile data. Figures 6 (10 to 19 km), 9 (8 to 17 km), and 10 (7 to 17 km) show some oscillations in wind speed profiles. It is not uncommon to find recurring oscillations in these data. The wind direction has some cyclic variations (Figs. 6a through 10a), some with wavelengths that are generally quite long (i.e., 1 to 2 km). When wind velocities are calculated over an altitude of approximately 50 m and printed-out every 25 m, the discernible wavelengths are on the order of 100-150 m as noted by Endlich et al. (1969:1030). An interesting feature is that periodic wave patterns occur in wind velocity profiles where the wavelengths increase or decrease systematically with altitude. Such wave patterns can increase the wind loads on a space vehicle in flight more than the fixed frequency wind variations, because the vehicle's acceleration may introduce a more precise wind-loads-coupling effect with the time-related structural and control frequency of the vehicle as reported by Ryan et al. (1967;1526); Fichtl et al. (1969b:1396); Kaufman and Susko (1971:6489); Johnson and Vaughan (1978:3).

2.1.3 Jet Stream Winds

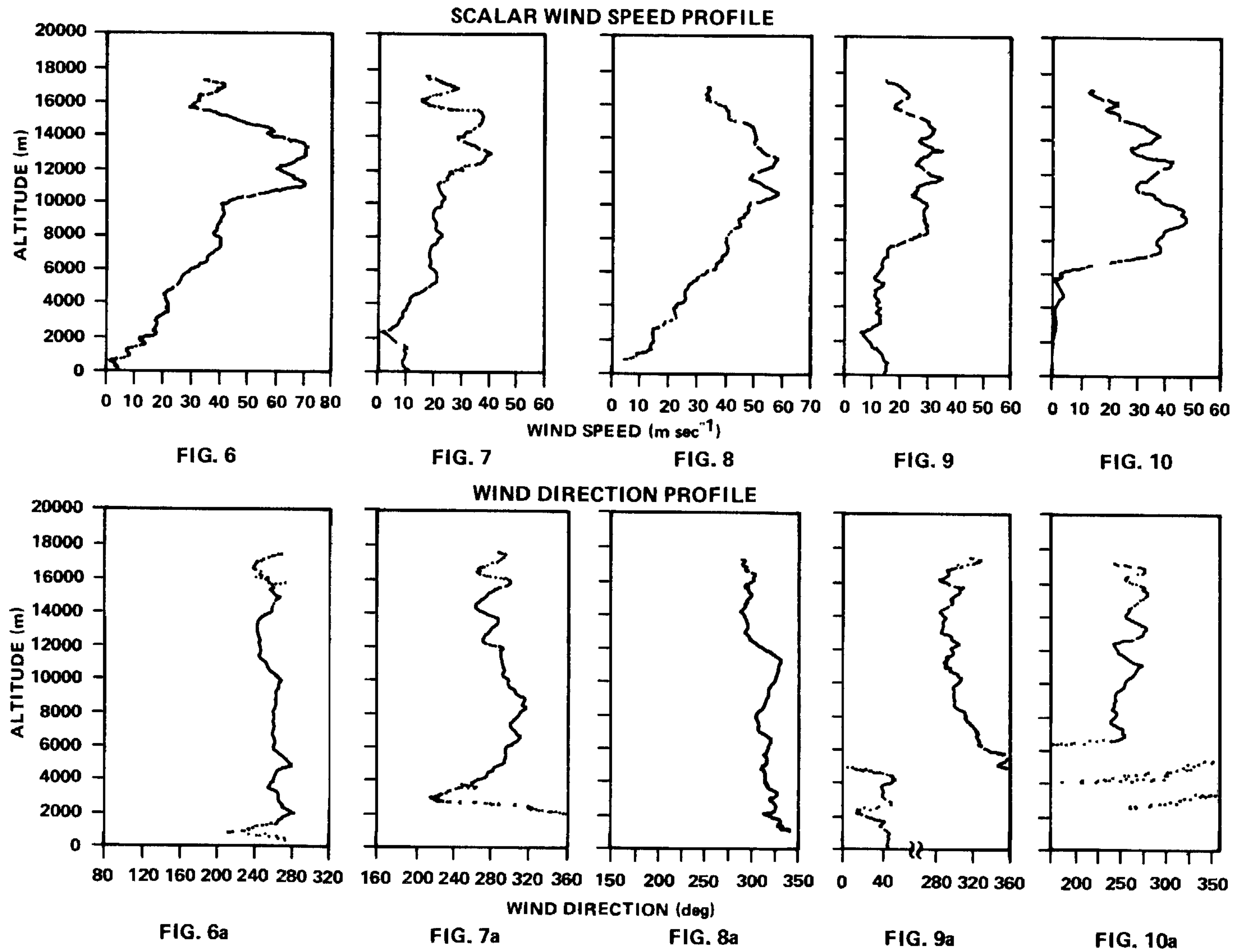
The relatively strong winds of the jet stream extend over a narrow height interval and are embedded in the mid-latitude westerlies in the troposphere (Reiter and Davies, 1966:43). Examples of jet-stream winds are depicted in Figures 11 through 15. The wind directions for the jet stream winds are presented in Figures 11a through 15a. Space vehicles and rockets flying through such high wind-speed-profile conditions experience high dynamic pressures as indicated by Kaufman and Susko (1971:6489); Hill (1986:3).

2.1.4. High Winds (Thick Layers)

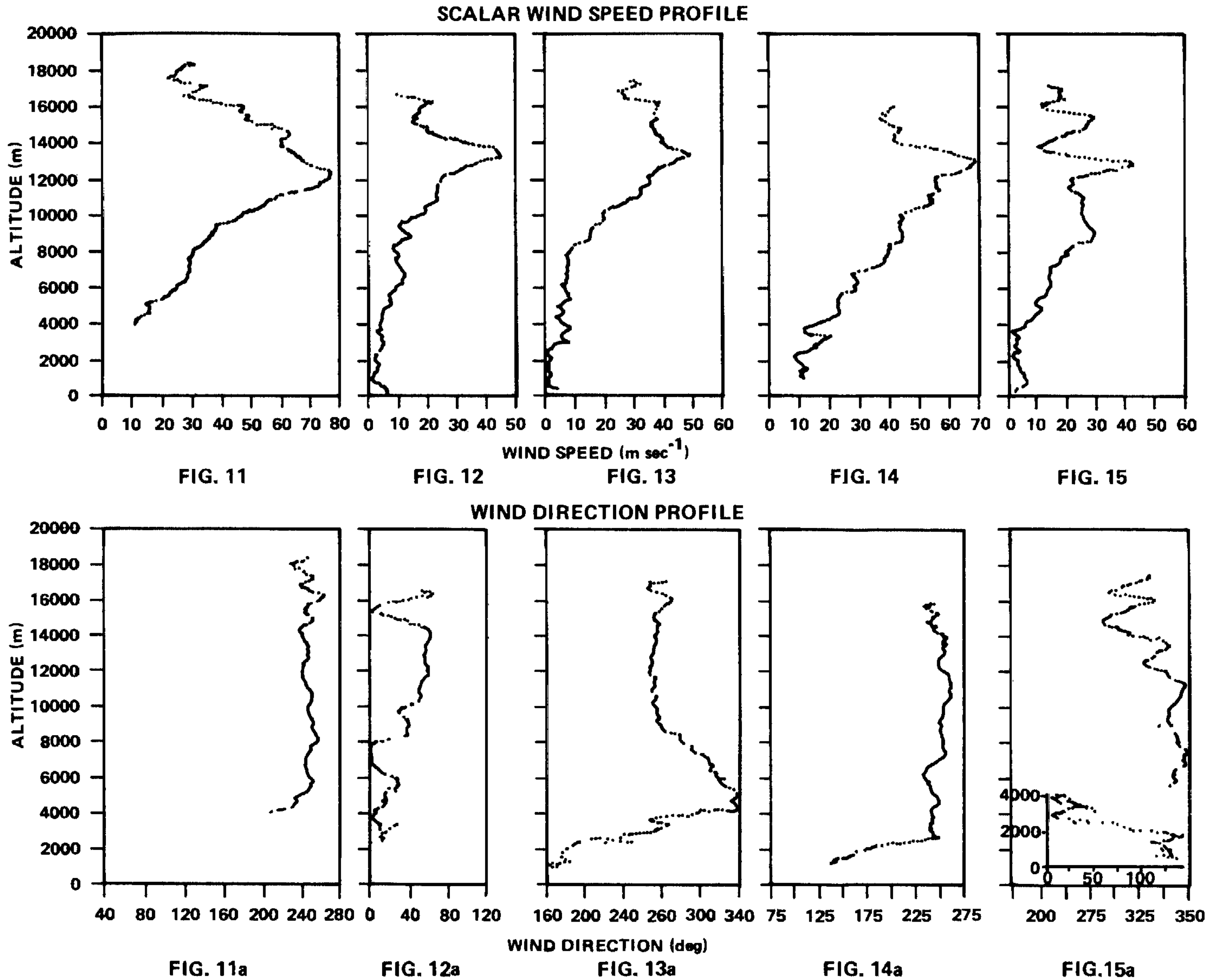
Another interesting feature in wind profiles is the relatively thick layer of high winds where speeds approach values of 70 to 80 m/s. Such high winds may commence at an altitude of 7 to 8 km and extend as high as 16 km. Space vehicles subjected to such winds may experience large responses. If extreme wind shears are associated with these high wind speeds, vehicle flight through such wind conditions becomes of concern and, therefore, detailed prelaunch vehicle simulations to the measured winds are accomplished as reported by Vaughan (1968:41); Fichtl (1969a:55). Summer winds for the Kennedy Space Center area are not a serious threat with respect to inflight wind loading on NASA's large space vehicles. The ground wind anomalies associated with thunderstorms and other unstable weather are the only conditions of consequence in launching from KSC in the summer as indicated by Vaughan (1968:41); Kaufman and Susko (1971:6489); and Johnson and Vaughan (1978:3).

2.1.5 Vertical Wind Motion

Vertical wind motions in the atmosphere are very easily detected by the FPS-16 Radar/Jimsphere System, as described by Endlich et al. (1969:1030); Fichtl et al. (1969b:1396); De Mandel and Krivo (1970:313); Kaufman and Susko (1971:6489); Johnson and Vaughan (1978:3); Hill (1986:3). By means of low-pass filtering, high frequency noise introduced by the FPS-16 radar is eliminated from the vertical rise rate Jimsphere data. The remaining perturbations may be representative of the induced vertical motions. Normally the Jimsphere rises about 5 m/s from sea level to 16 km as described by Scoggins (1964:591); MacCready and Jex (1964:10); Vaughan (1968:41); Susko and Kaufman (1973a:10); Johnson and Vaughan (1978:3); Hill (1986:3). MacCready and Jex (1964:10) stated that the value of the drag coefficient is of primary importance in computing the response of a Jimsphere or any other balloon to a change in wind speed. This was confirmed by Scoggins (1967:591) in his article "Aerodynamics of Spherical Balloon Wind Sensor." Kaufman and Susko (1971:6489) indicated that the drag coefficient is small at supercritical Reynolds number (Re) where the turbulent wake is small, but increases sharply in the transition region. The C_D is higher at subcritical Re where the wake is large and the flow is laminar.



Figures 6 through 10a are examples of peaked oscillations. The graphs show scalar wind speed and wind direction profiles versus altitude.



Figures 11 through 15a are examples of jet streams. The graphs show scalar speed and wind direction profiles versus altitude.

Jimsphere vertical rise rate data have been observed to vary from 2 to 10 m/s. Figure 16 illustrates some C_D versus Re values calculated for various vertical rise rates and the U.S. Standard Atmosphere 1962 temperature profile data. Figure 17 shows the following Jimsphere vertical rise rate data: profile A was observed from the Jimsphere, released at 1525Z, March 4, 1969 at Wallops Island, and profile B was observed from the Jimsphere released at 1933Z, March 5, 1969, also at Wallops Island. Profile A shows a typical 5 m/s rise rate from 10 to 12 km layer; whereas, profile B shows the rise rate to be about 8 m/s. The corresponding C_D versus Re values for profiles A and B are plotted in Figure 16, where the lower C_D at higher Re suggests a smaller turbulent wake downstream from the Jimsphere. This in turn suggests a layer of significant turbulence compared to turbulence of the adjacent air layers. Figure 18 shows the scalar wind-speed profiles A and B. Notice the jet stream wind speed of approximately 100 m/s between 10 and 12 km of profile B which relates to the resultant variation (turbulence) in the C_D versus Re values in Figure 16.

Turbulence is a state of flow "in which the instantaneous velocities exhibit irregular and apparently random fluctuations so that in practice only statistical properties can be recognized and subjected to analysis. These fluctuations often constitute major deformations of the flow, and are capable of transporting momentum energy and suspended matter at rates far in excess of the rate of transport by the molecular processes of diffusion and conduction in non-turbulent or laminar flow" (Huschke, 1959:598).

The wind variation depends on the sensitivity of instrumentation, time of measurements, and averaging. All of these factors affect the wind shear. Factors affecting the vertical motion of a zero-pressure polyethylene, free balloon were explored by Dwyer (1985). Because the balloon has no single characteristic length, a third dimensionless variable, fractional volume is needed. Its inconsistent shape and shape deformation further complicates the computation of Reynolds number, drag coeffecient, and the Froude number. The Jimsphere, however, is a constant 2 m diameter balloon as indicated by Scoggins (1967:591).

2.1.6 Sequential Wind Profiles

A composite of 12 FPS-16 Radar/Jimsphere balloon wind profile measurements from Kennedy Space Center, Florida, is illustrated in Figure 19. The sequential data set of winds varied over 24 hours with time separations of 1.5 to approximately 6 hr (Susko and Kaufman, 1973b:3). One hundred and twelve wind velocity profiles employing the FPS-16 Radar/Jimsphere System were presented by Scoggins and Susko (1965:10-121). These data were intended as a limited group of detailed wind profiles, and to provide a source for use by other research organizations. Seventy sequential Jimsphere wind profile data sets for Kennedy Space Center, Florida, from December 1964 to July 1970, were documented by Johnson and Vaughan (1978:3-98). These data illustrated the monitoring of the winds prior to launch of the space vehicle. The analysis of Jimsphere pairs for use in assessing space vehicle ascent capability was reported by Hill (1986:3).

III. DESCRIPTION OF JIMSPHERE AND WINDSONDE WIND SENSORS

A description of the FPS-16 Radar/Jimsphere System, a 2-m diameter, rigid roughened sphere constructed of a 0.5 mil aluminized mylar and tracked by a FPS-16 radar, a high precision C-band monopulse tracking radar is given in Section 3.1. Section 3.2 presents the Meteorological Sounding System (MSS) Windsonde which has been developed to replace the older and less accurate [AN/GMD-(X)] System which has been used for the last 30 years to acquire upper air data. This also replaces the GMD-2 rawin set which measures and records, at a frequency of 10 per minute, the following parameters: elapsed time of observation (min), elevation angle (deg), azimuth angle (deg), slant range (yards), and height above ground (feet). These details were described by Weidner (1965); Camp and Susko (1966).

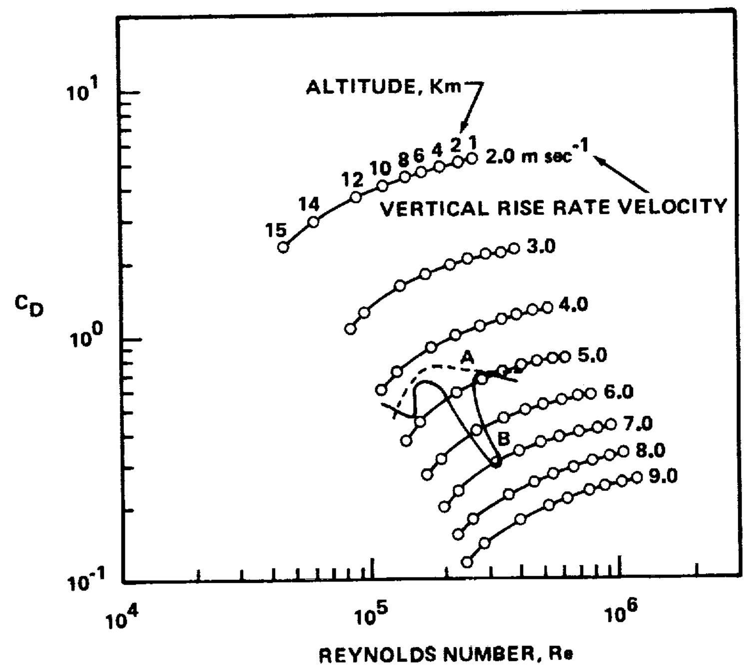


Figure 16. Idealized C_D versus Re curves as calculated from standard atmospheric data, and results calculated from Jimsphere release A, March 4, 1969 (1525Z) and release B, March 6, 1969 (1933Z).

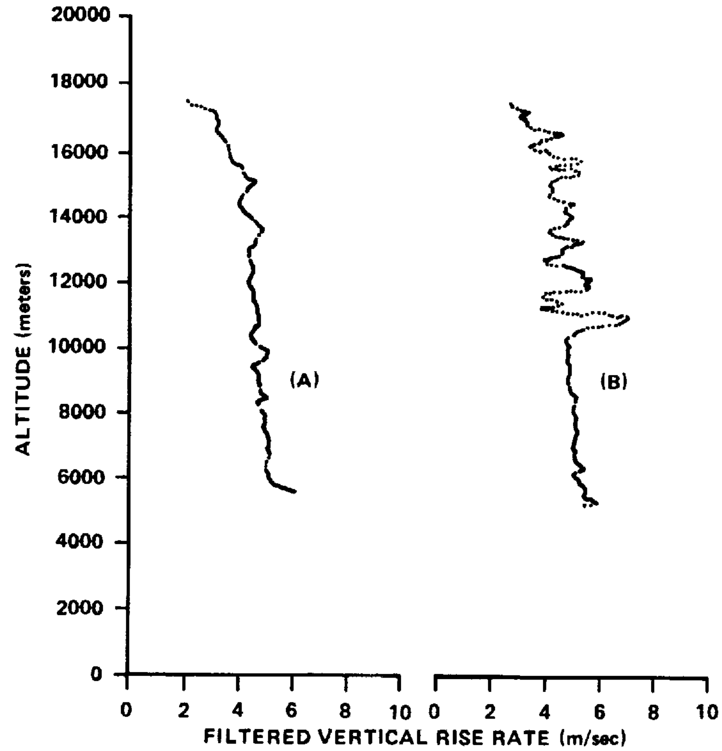


Figure 17. Vertical rise rate data of Jimsphere releases at Wallops Station, Virginia. Jimsphere A was released on March 4, 1969 (1525Z). Jimsphere B was released on March 6, 1969 (1933Z).

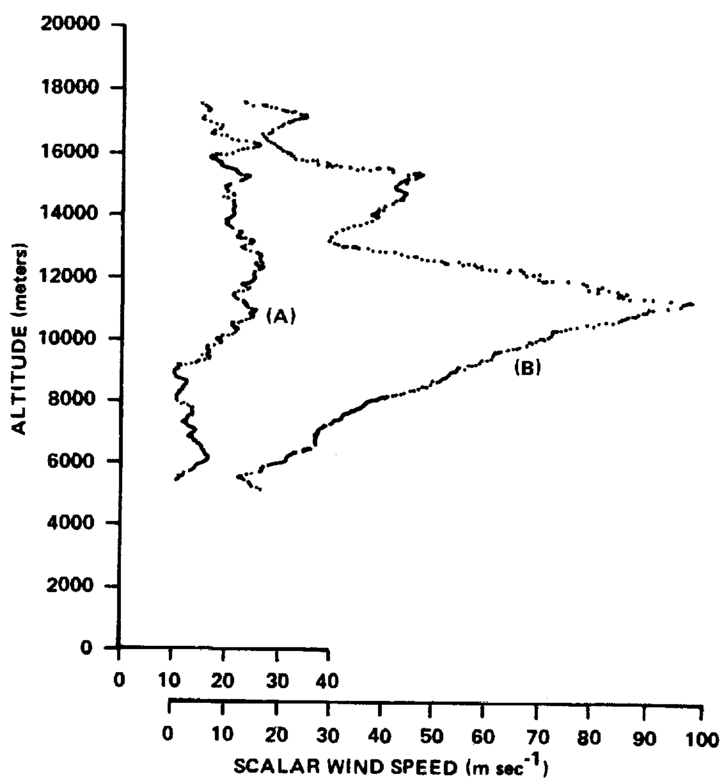


Figure 18. Vertical wind profiles measured by the FPS-16 Radar/Jimsphere at Wallops Island, Virginia. Jimsphere A was released on March 4, 1969 (1525Z). Jimsphere B was released on March 6, 1969 (1933Z).

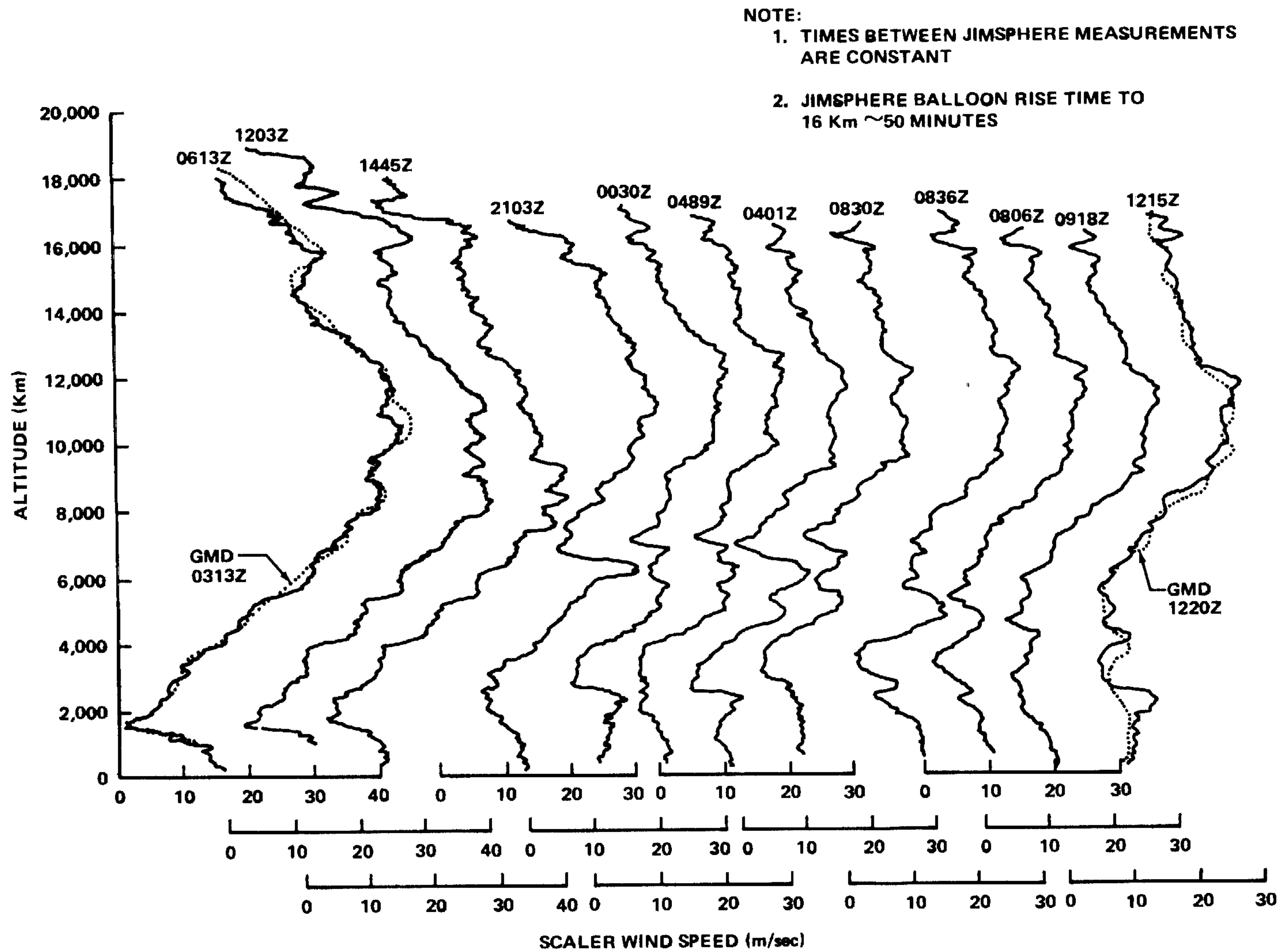


Figure 19. Composite of 12 FPS-16 Radar/Jimsphere Balloon wind profile measurements, Kennedy Space Center, Florida (ETR) November 8 and 9, 1967, scalar wind versus altitude.

3.1 FPS-16 Radar/Jimsphere System

Wind sensors of a more or less spherical shape have been employed for many years. Winds are normally measured by tracking a helium-or-hydrogen-filled neoprene or rubber balloon which expands as it uses. Positions of the balloon in space are determined by tracking it with radar or theodolites. Wind profile data are averaged over an altitude layer of 600 m or more. This averaging process eliminates small-scale motions which would be indicated if the balloon was tracked precisely. Therefore, for making such averaged measurements, it is not necessary that the aerodynamics of the sensor be accurately known. However, if accurate measurements are to be made at close intervals in space so that small-scale motions can be determined, the aerodynamic properties of the wind sensor must be established (Scoggins, 1964:591).

It has been known for many years that horizontal wind speeds in the atmosphere are many times larger than vertical wind speeds. For design and flight testing of vertically rising vehicles, particularly the larger types, it is important that the detailed characteristics of the wind field be specified in a vertical direction (Scoggins, 1964:591). A superpressure mylar constant volume sphere to be used as a wind sensor, and tracked by a precision radar, AN/FPS-16 was proposed by Getler (1962:15). An analysis of the response characteristics of the sphere, assuming a constant drag coefficient, showed the sphere's response is adequate to represent small-scale features of the wind field (Leviton 1962:187). Similar tests were described and made at NASA, Marshall Space Flight Center by Johnson (1962) and Scoggins (1963). Tests confirmed previous results that smooth balloons rise erratically in a calm atmosphere. Smooth superpressure balloons do not provide accurate detailed wind profiles. The response characteristics can be improved by the addition of roughness elements on a spherical balloon to stabilize the drag force vector and reduce the lift force. Spurious aerodynamically induced motions are significantly reduced, and the balloon more accurately senses the true wind (Scoggins, 1964:591).

The FPS-16 Radar/Jimsphere System winds data are obtained by tracking a super pressure aluminized mylar balloon with the FPS-16 radar as noted by Scoggins (1963:97-100); Scoggins and Susko (1965:2-458); Susko and Vaughan (1968:2-36); Johnson and Vaughan (1978:2-465); Hill (1986:3). The Jimsphere is tracked by the FPS-16, a high precision C-band monopulse tracking radar, which measures the balloon's position coordinates (range, azimuth angle) at 0.1 sec time intervals from near the surface to 18 km (DeMandel and Krivo, 1970:313-319). The sphere is a passive target and contains no instrumentation. The position of the sphere is obtained at 0.1 sec and processed to obtain wind speeds averaged over 50 m in altitude and given at 25 m intervals.

The Jimsphere balloon is a 2 m diameter, rigid roughened sphere constructed of a 0.5 mil aluminized mylar. Rigidity is provided by maintaining an internal overpressure of 5 mb, controlled by two spring-loaded plastic pressure relief valves. The balloon's 398 conical roughness elements serve to control vortex shedding, thereby reducing the amplitude and spectral bandwidth of aerodynamically induced balloon motions (Scoggins and Susko, 1965:2). Figure 20 illustrates the Jimsphere wind sensor. Figure 21 presents the operation of the FPS-16 Radar/Jimsphere System, (Hill, 1986:3).

The data reduction method used in evaluating the FPS-16 Radar/Jimsphere System data was developed by Scoggins (1964:591-598). The data reduction method edits the 0.1-sec radar measurements for wild points, converts from spherical to Cartesian coordinates, smoothes each coordinate over 4-sec time intervals centered at 25 m altitude increments, and computes velocity components from 50 m centered differences of the smoothed position coordinates.

Because of the low inertia of the balloon (weight of the balloon excluding gas is approximately 400 grams) and high drag characteristics, it responds readily to small-scale features of the wind field. This rapid response of the sensor combined with the superior tracking capabilities of the FPS-16 radar provide wind speeds with an RMS vector error of less than 0.5 m/s. This was determined from simultaneous radar tracks of the same balloon (Susko and Vaughan, 1968:2-36). Rawinsonde (GMD-1) measured wind speeds are averaged over approximately 600 m in the vertical direction and have an RMS vector error ranging between approximately 2 and 15 m/s depending on the

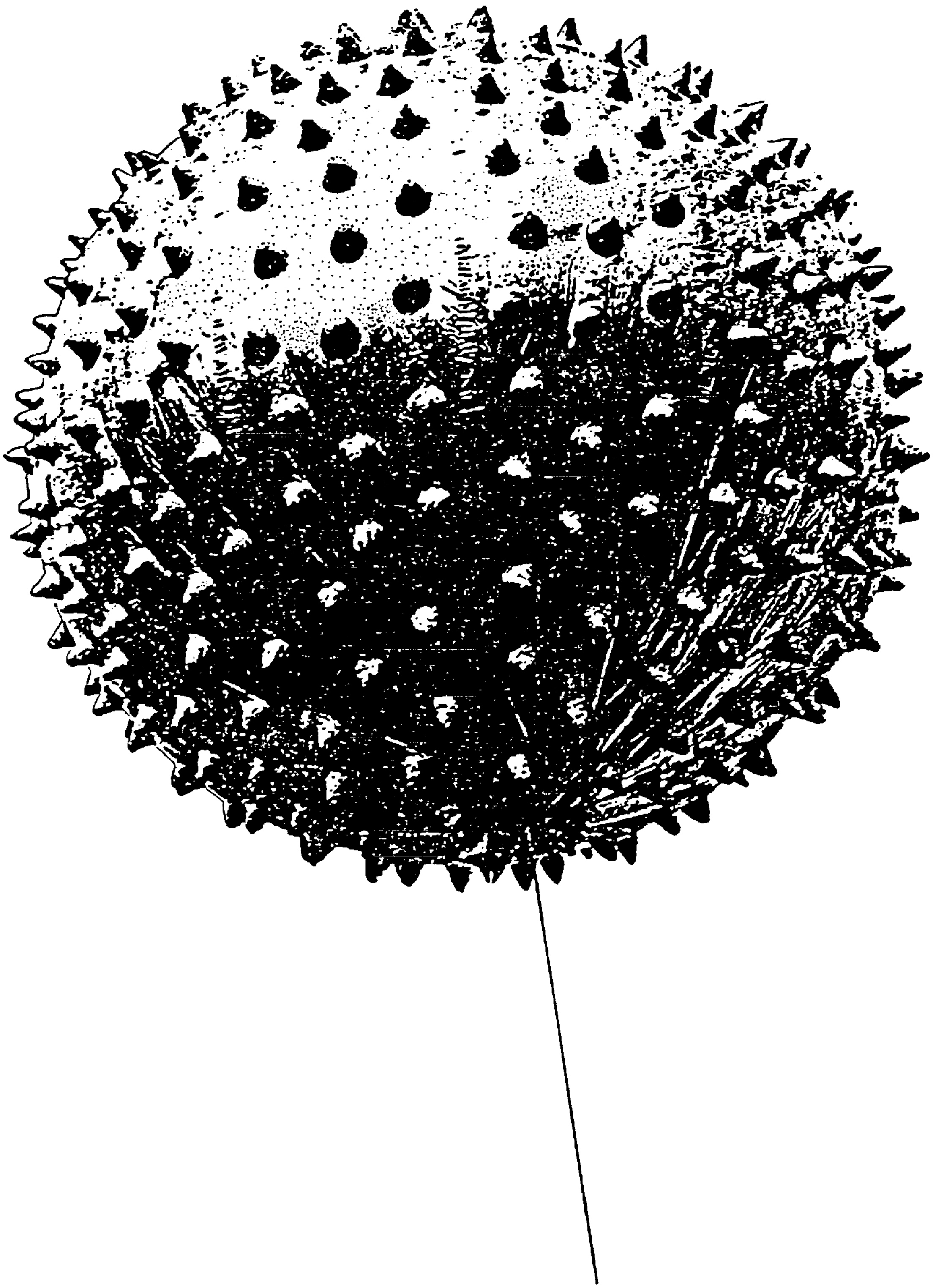


Figure 20. Jimsphere sensor.

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wind speed. Thus, the altitude resolution and accuracy of the wind velocity as measured by the FPS-16 Radar/ Jimsphere System are an order of magnitude better than those measured by the Rawinsonde Balloon (Scoggins and Armendariz, 1969:449-52), and reported by Susko (1977:11). This improved accuracy of the Jimsphere is attributed to 398 conical roughness elements with diameters of 7.62 cm at the base and 7.62 cm high randomly spaced over the surface of the balloon, which serves to control the vortex shedding and reduce the amplitude of the induced motions.

The roughness elements, combined with a mass of 100 grams, is sewed into the load patch to provide a displacement of the center of the mass, provide aerodynamic stability, and large drag. Although this design eliminates a large part of the aerodynamically induced motions, the Jimsphere still contains a spiral mode of oscillation with a period of approximately 4.5 sec as revealed by Doppler radar. The oscillation is not believed to be of significance in measuring winds for two reasons: (1) the FPS-16 radar does not measure these motions accurately, and (2) the radar position coordinates are smoothed over 4 sec in time, which reduces the spiral motion which enters into part of the error.

RMS errors were obtained by tracking a Jimsphere simultaneously with two FPS-16 radars. Thirty dual tracks from Kennedy Space Center, FL, Pt. Mugu, CA, and Green River, Utah, were conducted to obtain a better understanding for the operational accuracy of the FPS-16 Radar/Jimsphere System. Contributing to the RMS error of the Jimsphere are the condition of the radar, operator's experience, data editing, and the angular position of the balloon. The RMS error is approximately 0.5 m/s or less (including the spiral motion which is part of the error) for the component wind speeds: zonal (V_x) and meridional (V_y), the scalar wind speeds (V) and vertical velocity of the balloon (V_z) for elevation angles above 10 degrees and a slant range of 100 km (Susko and Vaughan, 1968:2-36).

Several tests at Kennedy Space Center were obtained when the slant ranges were beyond 100 km. From 100 to 132 km at the elevation angles (8.0 to 5.9 degrees), the RMS error wind speed error values ranged from 0.48 to 0.72 m/s. These larger values may be attributed to relatively poor radar performance at low elevation angles and greater slant ranges. Special attention to the careful selection of the radar settings (servo-bandwidths, etc.) and calibrations can improve the tracking data characteristics. This improvement may be desirable for certain research activities.

The means of the RMS errors computed from values at 2 km layers up to 18 km altitude for V_x, V_y, and V_z were obtained from seventeen cases at Kennedy Space Center, FL. The range of RMS error was 0.31 to 0.37 m/s. Similarly, the means of the RMS errors computed fom twelve cases at Green River varied from 0.17 to 0.21 m/s, and the one case at Pt. Mugu had an RMS error range of 0.24 to 0.35 m/s (Susko and Vaughan, 1968:2-36).

A comparison of simultaneous aircraft and Jimsphere upper wind measurements was made by a Doppler radar-equipped aircraft and radar tracking of a Jimsphere balloon. The measurements were made near Wallops Island, VA by the joint Air Force-NASA radar facility and a T-33 aircraft from the National Aeronautical Establishment, Canada. A by-product of the program was the comparison of the accuracy and fidelity of vertical wind profiles obtained from two widely different techniques. A major difference between the two methods is that the Jimsphere translates with the magnitude and direction of the mean flow whereas the T-33 aircraft moves in a predetermined direction at its true air speed plus the wind vector. However, provided the measurements are made reasonably close together in space and time and that longitudinal fluctuations in the mean flow are not significant, then the comparison should still be valid (Treddenick, 1971:309-12).

Numerous sources of error are present in each system. The accuracy of winds computed over 50 m layers is affected most significantly by: (1) excessive noise and nonstationarity of the raw radar data, (2) stray points and data shifts that elude the editing/smoothing procedure, (3) lag in the radar antenna response, and (4) erratic balloon motions.

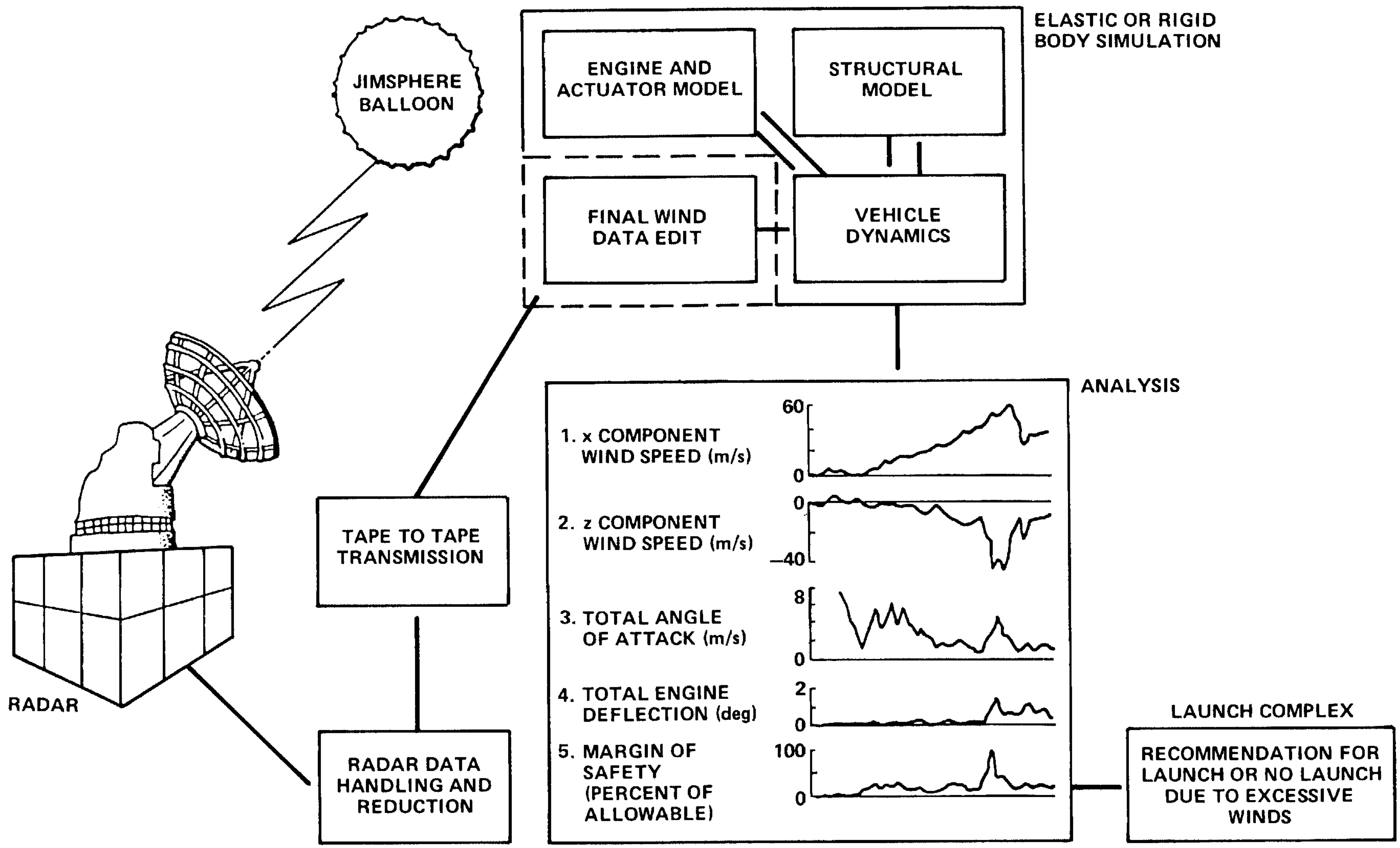

Figure 21. Operation of the FPS-16 Radar/Jimsphere System.

In the aircraft-Doppler system errors of wind measurement arise from errors in the ground speed vector as measured by the Doppler radar and also from errors in the true airspeed, altitude, total temperature, and magnetic heading. The Doppler radar in the T-33 can determine ground speed and drift angle to within less than 1 percent. These factors combine to produce RMS wind speed errors of less than 1.5 m/s. The RMS difference between aircraft and Jimsphere measured winds were less than 2.0 m/s. Treddenick (1971:309) concluded that the observed difference could be adequately explained by measurement errors.

3.2 Meteorological Sounding System (MSS) Windsonde

A procedure has been developed to track and acquire data from meteorological radiosondes, rocketsondes, windsondes, meteorological satellites, and remotely piloted vehicles [The Meteorological Sounding System (MSS) Standard Operating Procedures, 1984]. A single-channel monopulse tracking antenna is driven by a specially designed direct torque pedestal to provide accurate, reliable, and unambiguous slant range data. Automatic digital data processing and reduction are performed with a NOVA 3/12 minicomputer system. The system is compatible with existing radiosondes and rocketsondes, and fully automated data reduction is provided with the newly developed MSS high precision radiosondes and windsondes. The MSS has been developed to replace the older and less accurate AN/GMD-(X) systems used for the last 30 years to acquire upper air data. The MSS is a completely solid-state design that offers a significant improvement in accuracy, reliability, and maintainability over the gear-driven, vacuum tube designs as described by Engler and Felt (1983:10).

The tracking accuracy and antenna-pedestal design requirements for a Meteorological Sounding System (MSS) should be based upon the accuracy requirements for the meteorological data (Daniels, 1978:190-94). It is not a simple task, however, to relate the meteorological data accuracies to the tracking precision since trajectory variables, operating conditions, flight equipment, and data smoothing influence the results. For instance, low-angle tracking under high wind conditions generally results in maximum positioning errors as described by Susko and Vaughan (1968:2-36). Also, there is a direct relationship among data smoothing intervals, measurement fine structure, and accuracy.

The engineering issues considered in the system design consist of antenna size and efficiency, expected rf signal-to-noise ratios, servo system characteristics, pedestal stiffness and load inertia, wind-loading, tracking velocities and accelerations, sidelobe supression, available driving torques, and related factors. Figure 22 illustrates the Meteorological Sounding System (MSS) Windsonde.

3.3 Summary of Meteorological Wind Error Estimates of Jimsphere and Windsonde

A summary of meteorological data error estimates for the Jimsphere and Windsonde wind sensors is presented in Table 3 (Meteorological Group, 1981). Listed are the range of altitude measurements and the error estimates.

IV. JIMSPHERE AND WINDSONDE STATISTICS

This section presents the wind statistics for the FPS-16 Radar/Jimsphere System and the Meteorological Sounding System (MSS) Windsonde. The Jimsphere is the standard used to measure the ascent wind loads during the Space Shuttle launches at Kennedy Space Center (KSC), Florida, and the Windsonde is the backup. A statistical analysis of the bivariate parameter differences between the 64 pairs of Jimsphere and Windsonde measurements has been included in this section. A list of the date and time of these Jimsphere and Windsonde balloon releases, which supported 14 Space Shuttle launches, and the time of the launch of the Space Shuttle is given. The statistics of differences in the wind components, the buildup and back-off shears, the wind speed changes over various scales of distance, and the power spectral density (PSD) are presented.

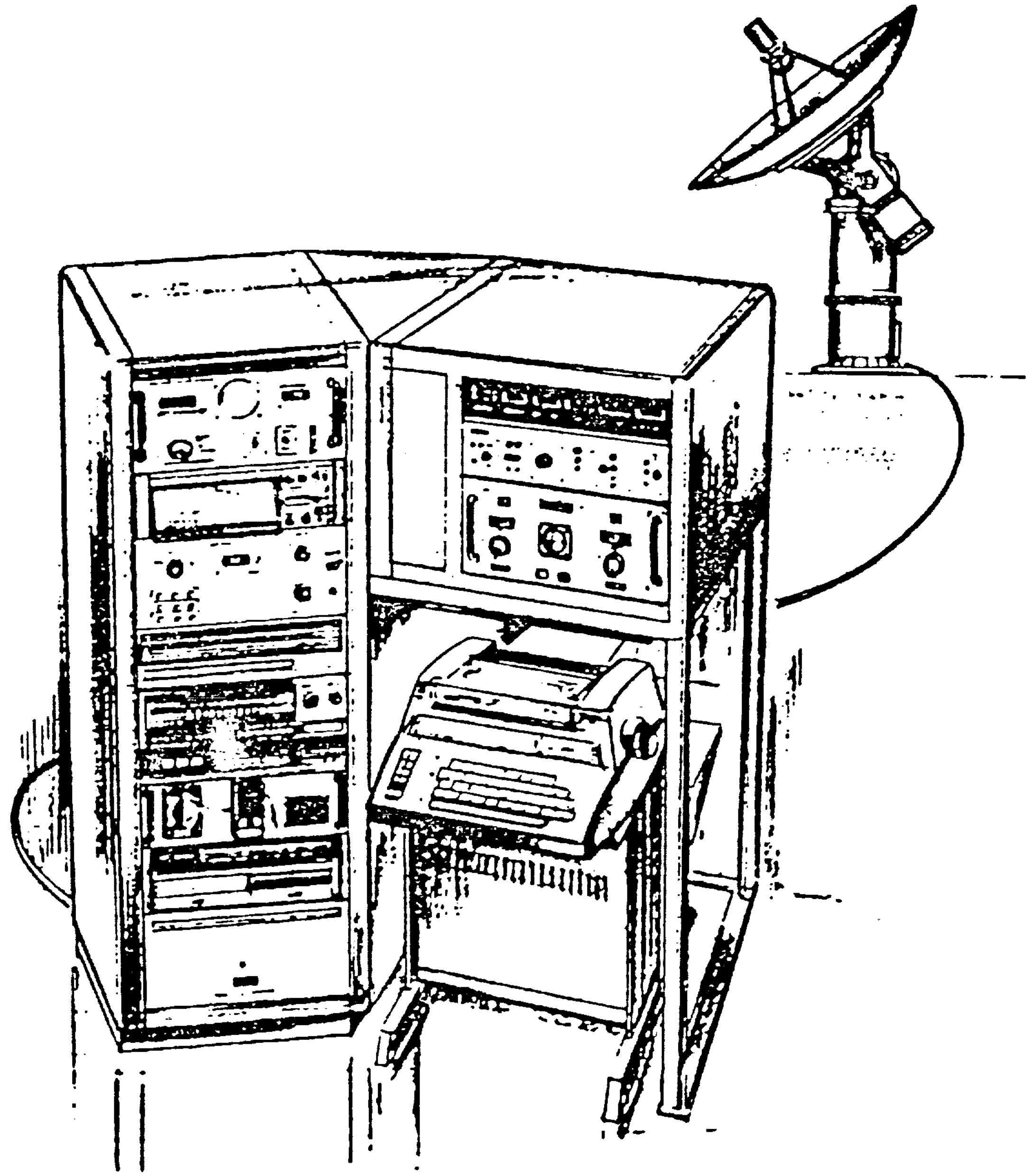

Figure 22. Meteorological Sounding System (MSS) Windsonde.

TABLE 3. METEOROLOGICAL DATA ERROR FOR JIMSPHERE AND WINDSONDE METEOROLOGICAL GROUP

PARAMETER AND INSTRUMENTATION TYPES	ALTITUDE OF MEASUREMENT	ERROR ESTIMATES
MSS WINDSONDE USING 300 – 600 gm BALLOON	SURFACE TO 25 km ALT. (60 m MEAN LAYER WINDS)	0.7 m/s VECTOR ERROR ESTIMATES, PLUS 1% OF VECTOR WIND
ROSE/JIMSPHERE USING USING FPS-16 OR EQUIVALENT	SURFACE TO 18 km ALTITUDE (50m MEAN LAYER WIND)	0.5 m/s VECTOR ERROR ESTIMATES, PLUS 1% OF VECTOR WIND

4.1 Comparison of Pairs of Jimsphere/Windsonde Statistics

During the shuttle launches at Kennedy Space Center, Florida, the Jimsphere is the standard wind sensor and the Windsonde is the backup. A statistical analysis of the bivariate parameter differences between the 64 pairs of Jimsphere and Windsonde soundings has been computed. The wind profiles supported 14 Space Shuttle launches (STS 41-B to STS 61-C) from February 2, 1984 to January 12, 1986. Table 4 lists the 64 pairs of Jimsphere/Windsonde balloon releases, giving a sum of 128 balloon releases for the analysis. The type 1 designates that a Jimsphere was released to measure the winds, and type 2 indicates that a Windsonde measured the winds. The year, month, day, and hour of the balloon released at KSC are given. The launch time of the Space Shuttle is also listed.

4.1.1 Analysis of Zonal and Meridional Wind Components

The statistical analysis of the zonal and meridional wind components for the Jimsphere and Windsonde shows good agreements. Table 5 lists the computed difference values in m/s of the mean zonal wind, U BAR ($\overline{u}$) and the meridional wind, V BAR ($\overline{v}$) of the Jimsphere and Windsonde for 500 m intervals. In addition, the standard deviation (S.D.) of the zonal winds (SIGU), and meridional winds (SIGV), are listed for the Jimsphere and Windsonde. The ($\overline{U}$) and ($\overline{V}$) mean wind difference values from the surface to 16 km for the Jimsphere and Windsonde for 64 observations were 0.16 and 0.22 m/s respectively. Figure 23 is a plot of S.D. for the u and v component differences. As the plot illustrates, there is very good agreement between the two wind sensors.

4.1.2 Analysis of Buildup and Back-Off Wind Data for Various Scales of Distance (Layers)

Wind speed change is defined as the total magnitude (speed) change between the wind vector at the top and bottom of a specified layer, regardless of wind direction.

Wind shear is the wind speed change divided by the altitude interval. When applied to space vehicle synthetic wind profile criteria, it is frequently referred to as wind buildup or back-off rate, depending upon whether it occurs below (buildup) or above (back-off) the reference height of concern. Thus, a buildup wind values is the change in wind speed which a vehicle may experience while ascending vertically through a specified layer to the known altitude. Back-off magnitudes describe the speed change data as a function of reference level wind vector magnitude and geographic location [NASA, 1982].

Table 6 illustrates the altitudes where the largest buildup in wind speed for a ΔH (m) increment occurs for the Jimsphere Wind Sensor. For example, for a scale height of 100 m (ΔH) for the Jimsphere statistics of 64 wind profiles at a mean altitude of 10,895 m, the average wind speed, w (m/s) was 27.09 m/s. The buildup in wind speed positive, WSP (m/s) was 2.26 m/s for a 100 m ΔH. The back-off average in wind speed, W(m/s) was 26.78 m/s at a mean altitude of 14,167 m and a wind speed minus WSM (m/s) change of -2.48 m/s.

From the ΔH scale height of 100, 200, 400, 600, 800, 1000, 2000, 3000, 4000, and 5000, the buildup occurred at an average of 10,420 m for the ΔH (m), with an average of 2976 m. The range of buildup velocity was from 27.09 to 31.64 m/s. As the scale of distance (layer) increased from 100 to 5000 m, the wind speed change increased from 2.26 to 21.39 m/s.

The back-off in wind speed minus WSM (m/s), occurred at an average of 14,351 m. The S.D. ranged from 1562 m to 2595 m with an average of 1953 m. As the scale of distance (layers) increased from 100 to 3000 m, the wind speed for the back-off statistics decreased from -2.48 m/s to -12.98 m/s.

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TABLE 4. A TOTAL OF 128 BALLOON RELEASES (64 PAIRS OF JIMSPHERE AND WINDSONDE) SUPPORT 14 SPACE SHUTTLE LAUNCHES AT KSC

RECORD #	TYPE	YEAR	MONTH	DAY	HOUR(z)	ORBITER	TIME(z)	MO/DAY/YR
1	1	84	2	2	1200			
2	2	84	2	2	1200			
3	1	84	2	3	546			
4	2	84	2	3	608	STS 41-B	1300	2/3/84
5	1	84	2	3	930			
6	2	84	2	3	924			
7	1	84	4	5	1058			
8	2	84	4	5	1051	STS 11-C	1358	4/6/84
9	1	84	4	6	643			
10	2	84	4	6	658			
11	1	84	8	29	1035			
12	2	84	8	29	1029	STS 41-D	1341	8/30/84
13	1	84	8	30	520			
14	2	84	8	30	535			
15	1	84	8	30	905			
16	2	84	8	30	859			
17	1	84	10	5	348			
18	2	84	10	5	403	STS 41-G	1203	10/5/84
19	1	84	10	5	752			
20	2	84	11	5	725			
21	1	84	11	5	1118			
22	2	84	11	5	1112			
23	1	84	11	6	1122			
24	2	84	11	6	1116			
25	1	84	11	7	22			
26	2	84	11	7	16			
27	1	84	11	7	608			
28	2	84	11	7	623	STS 51-A	1215	11/8/84
29	1	84	11	7	941			
30	2	84	11	7	944			
31	1	84	11	7	1440			
32	2	84	11	7	1435			
33	1	84	11	8	500			
34	2	84	11	8	515			
35	1	84	11	8	845			
36	2	84	11	8	831			
37	1	85	1	22	1615			
38	2	85	1	22	1609			
39	1	85	1	23	1615			
40	2	85	1	23	1609	STS 51-C	1740	1/24/85
41	1	85	1	24	515			
43	1	85	1	24	1100			
44	2	85	1	24	1117			
45	1	85	4	11	1104			
46	2	85	4	11	1058			
47	1	85	4	12	4			
48	2	85	4	11	2358	STS 51-D	1359	4/12/85
49	1	85	4	12	549			
50	2	85	4	12	604			
51	1	85	4	29	300			
52	2	85	4	29	254			
53	1	85	4	29	845	STS 51-B	1600	4/29/85
54	2	85	4	29	908			
55	1	85	4	29	1230			
56	2	85	4	29	1224			
57	1	85	6	17	418			
58	2	85	6	17	433			
59	1	85	6	17	803	STS 51-G	1133	6/17/85
60	2	85	6	17	754			
61	1	85	7	12	730			
62	2	85	7	12	724			
63	1	85	7	12	1315	DELAYED		
64	2	85	7	12	1332			
65	1	85	7	12	1700			
66	2	85	7	12	1653			
67	1	85	7	28	1448			
68	2	85	7	28	1442			
69	1	85	7	29	548			
70	2	85	7	29	542	STS 51-F	2100	7/29/85
71	1	85	7	29	1133			
72	2	85	7	29	1148			
73	1	85	10	2	1020			
74	2	85	10	2	1014			
75	1	85	10	3	120			
76	2	85	10	3	114	STS 51-G	1515	10/3/85
77	1	85	10	3	705			
78	2	85	10	3	720			
79	1	85	10	29	1200			
80	2	85	10	29	1154			
81	1	85	10	30	400			
82	2	85	10	30	354			
83	1	85	10	30	945	STS 61-A	1700	10/30/86
84	2	85	10	30	1003			
85	1	85	10	30	1447			
86	2	85	10	30	1500			
87	1	85	11	25	1829			
88	2	85	11	25	1826			
89	1	85	11	26	1129			
90	2	85	11	26	1120	STS 61-B	1829	11/26/85
91	1	85	11	26	1714			
92	2	85	11	26	1728			
93	1	85	11	26	2059			
94	2	85	11	26	2053			
95	1	85	11	26	2214			
96	2	85	11	26	2229			
97	1	85	12	18	1200			
98	2	85	12	18	1300			
99	1	85	12	18	2300			
100	2	85	12	18	2315	DELAYED		
101	1	85	12	19	445			
102	2	85	12	19	500			
103	1	86	1	5	2305			
104	2	86	1	5	2302			
105	1	86	1	6	450			
106	2	86	1	6	505			
107	1	86	1	6	838			
108	2	86	1	6	832			
109	1	86	1	6	2305			
110	2	86	1	6	2302			
111	1	86	1	7	450	DELAYED		
112	2	86	1	7	545			
113	1	86	1	7	835			
114	2	86	1	7	832			
115	1	86	1	9	1155			
116	2	86	1	9	1251			
117	1	86	1	9	2256			
118	2	86	1	9	2252			
119	1	86	1	11	1155			
120	2	86	1	11	1255			
121	1	86	1	11	2255			
122	2	86	1	11	2262			
123	1	86	1	12	440	STS 61-C	1155	1/12/86
124	2	86	1	12	455			
125	1	86	1	12	825			
126	2	86	1	12	822			
127	1	86	1	12	940			
128	2	86	1	12	955			

TOTAL NUMBER OF RECORDS = 128

TYPE 1 = JIMSPHERE
TYPE 2 = WINDSONDE

TABLE 5. KSC JIMSPHERE-WINDSONDE STATISTICS OF U AND V WIND COMPONENT DIFFERENCES

ALTITUDE (km)	UBAR ($\bar{u}$)	SIGU	VBAR ($\bar{v}$)	SIGV	NOBS
.0	.00	.0000	.00	.0000	64
.5	.26	2.5134	.07	2.2044	64
1.0	.25	2.5190	.07	2.5254	64
1.5	–.40	1.1049	–.01	.7122	64
2.0	.00	1.3154	–.02	.9329	64
2.5	–.12	.9018	.13	.9198	64
3.0	–.10	.8233	.13	.7876	64
3.5	–.11	.6541	.27	1.3070	64
4.0	–.02	.6312	.18	1.0600	64
4.5	.05	.8942	.17	1.5211	64
5.0	.02	.8465	.15	1.2468	64
5.5	–.04	.9057	–.02	.7969	64
6.0	–.11	.9983	–.03	1.1822	64
6.5	.04	1.1003	.15	1.4273	64
7.0	–.02	.7530	.03	1.5555	64
7.5	–.11	1.0431	.08	.9051	64
8.0	–.06	.9882	.13	1.3411	64
8.5	–.13	.7810	–.01	1.2883	64
9.0	.23	1.1452	.17	1.4704	64
9.5	–.30	1.2061	.22	1.3483	64
10.0	.10	.8236	–.08	1.2905	64
10.5	.05	1.2525	.13	1.2733	64
11.0	.11	1.0921	–.11	1.5767	64
11.5	.17	1.4594	–.17	1.7220	64
12.0	.03	1.2252	.23	2.6128	64
12.5	.33	1.4411	.63	1.9366	64
13.0	.28	2.2232	.39	2.7775	64
13.5	.14	1.5746	–.17	2.7036	64
14.0	–.68	3.0266	–.17	3.3015	64
14.5	–.15	1.9109	.54	2.3520	64
15.0	–.15	1.9507	.34	2.2928	64
15.5	–.56	2.2799	.92	2.9861	64
16.0	–.15	2.8177	1.00	3.3850	64

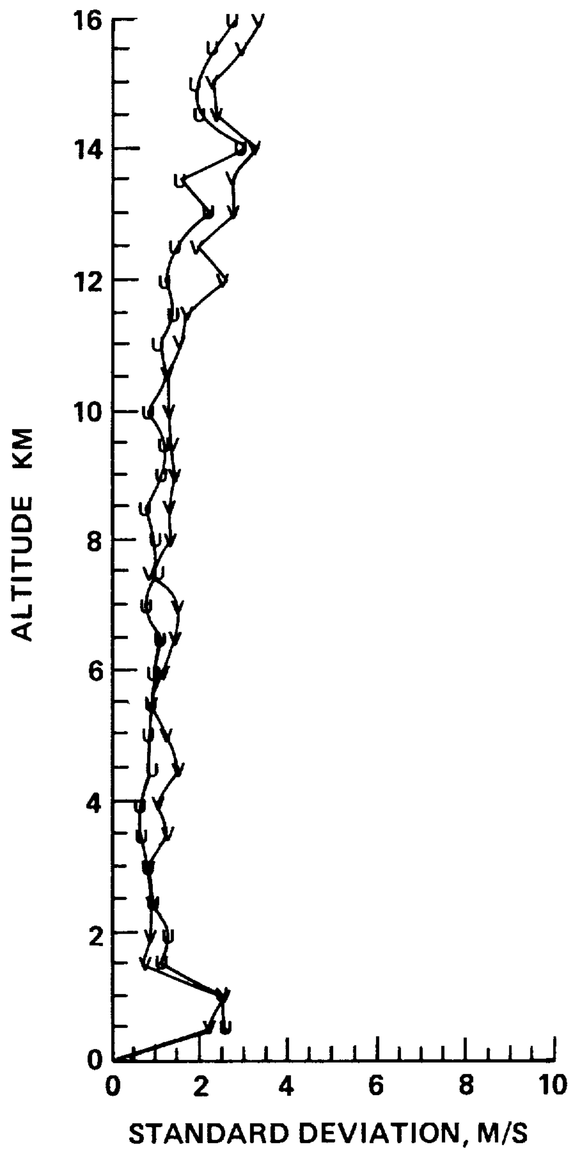

Figure 23. Standard deviation of meridional (u) and zonal (v) wind speed differences of Jimsphere and Windsonde wind sensors obtained at KSC.

Table 7 illustrates the altitudes where the largest buildup in wind speed for the Windsonde for a specific increment occurs. For example, for a scale height of 100 m, the average wind speed, W (m/s) was 28.66 m/s at an average altitude of 10,971 m. The buildup in wind speed positive WSP (m/s), was 2.39 m/s for a $\Delta H = 100$ m. The back-off in wind speed minus WSM (m/s), occurred at 14,117 m for an increment of 100m, with an average wind speed of 27.54 m/s and a back-off change of -2.48 m/s.

From the ΔH (m) of 100, 200, 400, 600, 800, 1000, 2000, 3000, 4000, and 5000, the buildup occurred at an average of 10,529 m ranging from 10,099 to 11,168 m. The S.D. average for the buildup statistics was 3029. As the scale of distance (layers) increased from 100 to 5000 m the wind speed change increased from 2.39 m/s to 21.40 m/s, in parallel with the similar increase in the Jimsphere data.

The wind speed minus or back-off in wind speed, WSM (m/s), occurred at an average of 14,374 m. The S.D. ranged from 1383 m to 2543 m with an average of 1938 m. The wind speed change for the back-off statistics decreased from -2.48 m/s to -12.64 m/s as the altitude increment increased from 100 to 3000 m.

Table 8 illustrates the altitudes for the largest buildup in wind speed for each increment occurring for the Jimsphere/Windsonde pairs. For example, for a scale height of 100 m for the 128 wind profiles the average wind velocity, W (m/s) was 27.88 m/s at a mean altitude of 10,933 m. The buildup in wind speed positive WSP (m/s) was 2.32 for a 100 m ΔH. At a mean altitude of 14,142 m, the average wind speed was 27.16 m/s and the back-off in wind speed minus was 2.48 m/s.

From the scale heights of 100, 200, 400, 600, 800, 1000, 2000, 3000, 4000, and 5000 m, the buildup occurred at an average altitude of 10,474 m. The average S.D. was 3007. The range of mean speed maximum, W (m/s) was from 27.88 to 31.79 m/s. As the scale of distance (layer) increased from 100 to 5000 Δm, the wind speed change positive WSP (m/s) increased from 2.32 to 21.39 m/s.

The back-off in wind speed, WSM (m/s) occurred at an average of 14,368 m. The S.D. average was 1938 m, ranging from 2622 to 3411 m.

The data from the Jimsphere/Windsonde pairs fell between the Jimsphere and Windsonde as an average should.

4.1.3 Summary of Buildup and Back-Off Data for Jimsphere, Windsonde, and Jimsphere/ Windsonde Pairs

For the ΔH (m) scale heights of 100, 200, 400, 600, 800, 1000, 2000, 3000, 4000, and 5000, the largest wind speed change and the altitude at which the largest change occurred were tabulated in tables 6, 7, and 8 for each of the scale heights for the Jimsphere, Windsonde, and the Jimsphere/Windsonde pairs. The two systems are in good agreement. For example, the average altitude where the greatest buildup occurred averaged over all scale heights was 10,427 m for the Jimsphere, 10,529 m for the Windsonde, and the Jimsphere/Windsonde pairs were 10,474; a difference of 102 m. Also, the S.D. of these parameters compared favorably at 2999, 3029, and 3007 m; a difference of 30 m.

Likewise, the average altitude where the greatest back-off for the above scale heights occurred was at 14,381 m for the Jimsphere and 14,374 m for the Windsonde, and the Jimsphere/Windsonde pair was 14,368 m. The S.D. compared exceptionally well at 1953, 1938, and 1946 m respectively. Table 9 lists the summary of the buildup and back-off data.

TABLE 6. THE STATISTICS OF THE BUILDUP AND BACK-OFF WIND DATA FOR VARIOUS SCALES OF DISTANCES OBTAINED FROM 64 JIMSPHERES, RELEASED AT KSC IN SUPPORT OF THE SPACE SHUTTLE'S LOADS ASSESSMENT

100 (Δ H)	ALT(M)	W(M/S)	WSP(M/S)	ALT(M)	W(M/S)	WSM(M/S)
MEAN	10895	27.09	2.26	14167	26.78	−2.48
S. D.	3165	15.39	.72	1800	16.22	.82
200 (Δ H)						
MEAN	10698	27.89	4.19	14635	26.00	−4.61
S. D.	3194	15.53	1.35	1562	16.50	1.61
400 (Δ H)						
MEAN	10189	29.26	6.72	14215	25.30	−7.52
S. D.	3350	16.24	2.34	1597	16.71	2.91
600 (Δ H)						
MEAN	10331	29.48	8.29	14150	24.60	−9.38
S. D.	3243	16.09	3.07	1652	16.36	3.80
800 (Δ H)						
MEAN	10304	29.41	9.34	14295	24.13	−10.19
S. D.	3019	15.22	3.58	1607	16.01	4.43
1000 (Δ H)						
MEAN	10165	30.30	10.15	14321	23.51	−10.84
S. D.	2843	15.93	3.89	1873	15.52	5.04
2000 (Δ H)						
MEAN	10250	29.57	13.74	14312	22.62	−12.12
S. D.	2984	14.78	5.74	2280	16.22	5.60
3000 (Δ H)						
MEAN	10183	29.88	16.59	14302	21.27	−12.98
S. D.	2835	13.77	7.77	2598	15.45	7.49
4000 (Δ H)						
MEAN	10290	30.04	19.15	14642	21.27	−12.11
S. D.	2638	13.85	9.47	2347	14.85	8.31
5000 (Δ H)						
MEAN	10896	31.64	21.39	14775	20.84	−9.36
S. D.	2496	14.61	11.20	2216	14.92	7.26

TABLE 7. THE STATISTICS OF THE BUILDUP AND BACK-OFF WIND DATA FOR VARIOUS SCALES OF DISTANCES OBTAINED FROM 64 WINDSONDE RELEASED AT KSC IN SUPPORT OF THE SPACE SHUTTLE'S LOAD ASSESSMENT

	ALT(M)	W(M/S)	WSP(M/S)	ALT(M)	W(M/S)	WSM(M/S)
100 (Δ H)						
MEAN	10971	28.66	2.39	14117	27.54	- 2.48
S. D.	3239	16.50	.80	1517	16.00	.75
200 (Δ H)						
MEAN	11168	29.17	4.36	14272	26.42	- 4.60
S. D.	3236	16.25	1.47	1383	15.81	1.46
400 (Δ H)						
MEAN	10590	28.57	6.88	14137	24.81	- 7.45
S. D.	3460	14.27	2.32	1803	15.39	2.77
600 (Δ H)						
MEAN	10741	29.97	8.40	14195	23.69	- 4.30
S. D.	3329	14.48	2.94	1843	15.07	4.02
800 (Δ H)						
MEAN	10099	28.99	9.39	14212	23.32	- 10.31
S. D.	3197	14.37	3.23	1838	14.84	4.77
1000 (Δ H)						
MEAN	10194	29.56	10.33	14444	23.24	- 10.77
S. D.	3026	14.61	3.52	1751	14.88	5.28
2000 (Δ H)						
MEAN	10426	30.62	14.04	14581	22.23	- 12.38
S. D.	2891	15.37	5.94	2275	15.46	6.06
3000 (Δ H)						
MEAN	10239	30.68	16.80	14343	21.10	- 12.64
S. D.	2883	14.34	7.94	2543	15.02	7.47
4000 (Δ H)						
MEAN	10045	29.68	19.12	14718	21.34	- 12.15
S. D.	2601	13.65	9.75	2250	14.49	8.82
5000 (Δ H)						
MEAN	10819	31.94	21.40	14729	20.98	- 9.30
S. D.	2455	14.67	11.26	2180	14.59	7.78

TABLE 8. THE STATISTICS OF THE BUILDUP AND BACK-OFF WIND DATA FOR VARIOUS SCALES OF DISTANCES OBTAINED FROM 64 JIMSPHERE/WINDSONDE RELEASED AT KSC IN SUPPORT OF THE SPACE SHUTTLE'S LOAD ASSESSMENT

100 (Δ H)	ALT(M)	W(M/S)	WSP(M/S)	ALT(M)	W(M/S)	WSM(M/S)
MEAN	10933	27.88	2.32	14142	27.16	- 2.48
S. D.	3203	15.98	0.76	1665	16.12	0.78
200 (Δ H)						
MEAN	10933	28.53	4.28	14318	26.21	4.61
S. D.	3224	15.90	1.41	1476	16.16	1.54
400 (Δ H)						
MEAN	10390	28.91	6.80	14176	25.06	−7.49
S. D.	3411	15.29	2.33	1704	16.06	2.84
600 (Δ H)						
MEAN	10536	29.73	8.34	14173	24.14	−9.34
S. D.	3292	15.31	3.01	1750	15.74	3.91
800 (Δ H)						
MEAN	10202	29.20	9.36	14254	23.72	- 10.25
S. D.	3111	14.80	3.41	1727	15.44	4.60
1000 (Δ H)						
MEAN	10179	29.93	10.24	14383	23.37	- 10.80
S. D.	2936	15.29	3.71	1814	15.20	5.16
2000 (Δ H)						
MEAN	10338	30.09	13.89	14487	22.42	- 12.25
S. D.	2939	15.09	5.84	2282	15.84	5.84
3000 (Δ H)						
MEAN	10211	30.29	16.69	14323	21.18	- 12.81
S. D.	2859	14.07	7.86	2571	15.24	7.48
4000 (Δ H)						
MEAN	10167	29.86	19.13	14680	21.30	- 12.13
S. D.	2622	13.70	9.61	2299	14.67	8.57
5000 (Δ H)						
MEAN	10858	31.79	21.39	14752	20.91	- 9.23
S. D.	2476	14.64	11.23	2198	14.76	7.52

4.1.4 Comparison of Cumulative Percent Frequency Versus Windspeed Change for Jimsphere, Windsonde, and Jimsphere/Windsonde Pairs

Figure 24 is a plot of wind speed change versus cumulative percent frequency for the Jimsphere, Windsonde, and Jimsphere/Windsonde statistics for various shear scales of distances (ΔH) of 100, 200, 400, 600, 800, 1000, 2000, 3000, and 5000 m. For example, at 75 percent on the abscissa or the horizontal scale (Cumulative Percent Frequency) the wind speed change is 20.5 m/s for a ΔH of 3000 m. This means that 75 percent of the time, the largest windspeed change over a 3000 m layer below 16 km is less than 20.5 m/s.

4.2 Power Spectral Density of Jimsphere and Windsonde

The power spectra presented in this report were obtained by Fourier Transformation of vertical height profiles of horizontal wind velocities. Such transformations produce power spectra that are a function of vertical wave number (inverse wavelength) as opposed to the usual frequency spectra, which are transformed time series. The abscissa of the spectral plot presented here is labelled both in wavenumber and in wavelength at the top of the graph. The ordinate is power spectral density in units of meters per second squared per wavenumber. Integration of the power spectral density over any wavenumber band yields the mean square amplitude of the waves in that band. Thus, a power spectrum gives information on the mean square contribution of different wavenumber bands to the power present in the original data.

4.2.1 Spectra of Jimsphere and Windsonde Components

Two regions can be clearly distinguished in Figures 25 and 26 which illustrate the u and v wind components of the Jimsphere and Windsonde. At wavelengths greater than 1500 m, there is relatively little power because the original profiles were digitally filtered to remove power at those wavelengths before the power spectrum was computed. From wavelengths of 1500 m down to wavelengths of 90 m, the spectra have roughly the same slope as the design curves.

4.2.2 Variance Difference Between Jimsphere and Windsonde

Figure 27 and figure 28 are the variance delta between the Jimsphere (number one) and Windsonde (number two). The Power Spectral Density was computed for both the Jimsphere and Windsonde. Variance was obtained at each wavenumber by multiplying PSD by wavenumber. The plot represents the variance difference from the Windsonde minus the Jimsphere. The plot comes from 128 different frequencies from each of the 64 pairs of Jimsphere and Windsonde, giving a total of 8192 variance differences for the u and v components as indicated previously. To the left of 1500 m the original profiles were digitally filtered to remove power at those wavelengths, and these data should be ignored. The u and v plots indicate that the variance difference or energy difference was very small, ranging from $\pm$ 0.02 m^2/sec^2. Also, the variance varies directly as the wavelength; the larger the wavelength the greater the variance value. Thus, over the wavelength range from 1500 to 90 m, the two measurement systems produce very comparable spectra as evidenced by the small variance difference.

TABLE 9. COMPARISON OF GREATEST VALUES OF BUILDUP AND BACK-OFF AVERAGES FOR JIMSPHERE, WINDSONDE, AND JIMSPHERE/WINDSONDE PAIRS FOR SCALE HEIGHTS OF 100, 200, 400, 600, 800, 1000, 2000, 3000, 4000, AND 5000 WHERE MAXIMUM WIND SPEED CHANGE OCCURRED

BUILDUP	JIMSPHERE	WINDSONDE	JIMSPHERE/ WINDSONDE PAIRS
ALT (m)	10427	10529	10474
S. D. (m)	2999	3029	3007
WIND (m/s)	29.45	29.78	29.62
S. D. (m/s)	15.14	14.85	15.00
BACK-OFF			
ALT (m)	14381	14374	14368
S. D. (m)	1953	1938	1946
WIND (m/s)	23.63	23.47	23.56
S. D. (m/s)	15.88	15.12	15.52

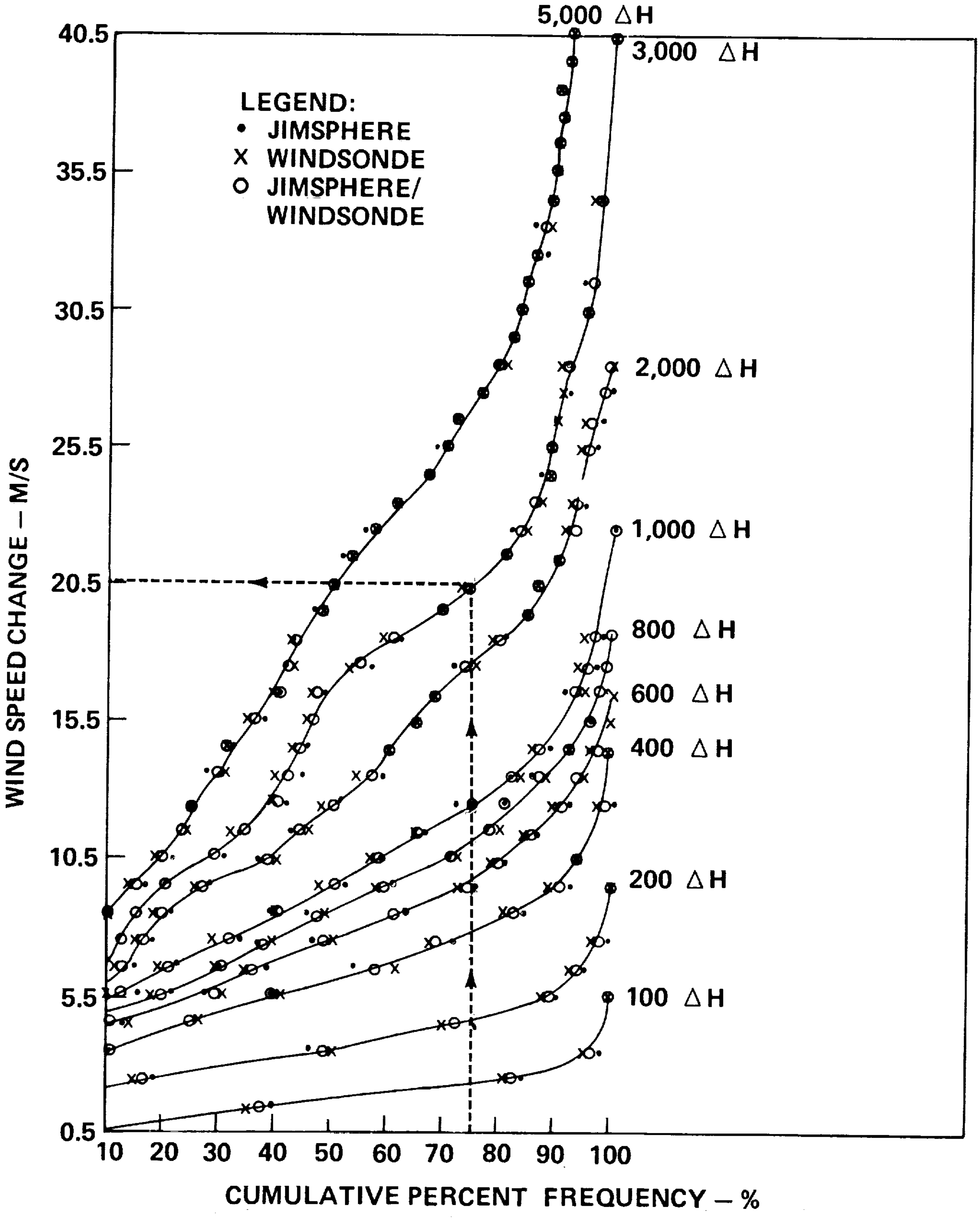

Figure 24. Wind speed change versus comparative cumulative percentage frequency for Jimsphere, Windsonde, and Jimsphere and Windsonde statistics for various shear altitudes.

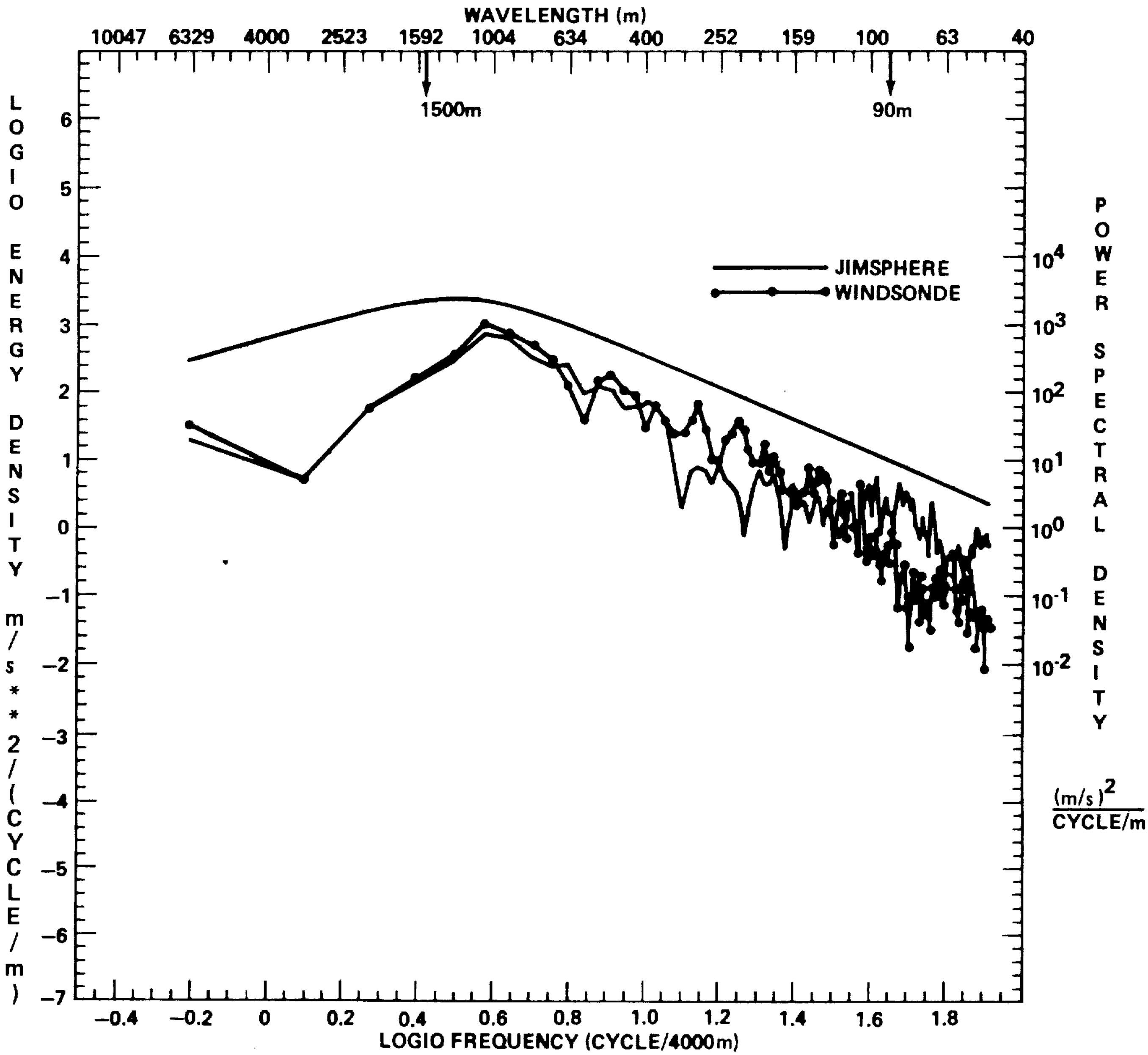

Figure 25. Spectra of Jimsphere and Windsonde, Zonal component for STS launch on October 5, time 0348Z (Jimsphere) and 0403Z (Windsonde) from KSC.

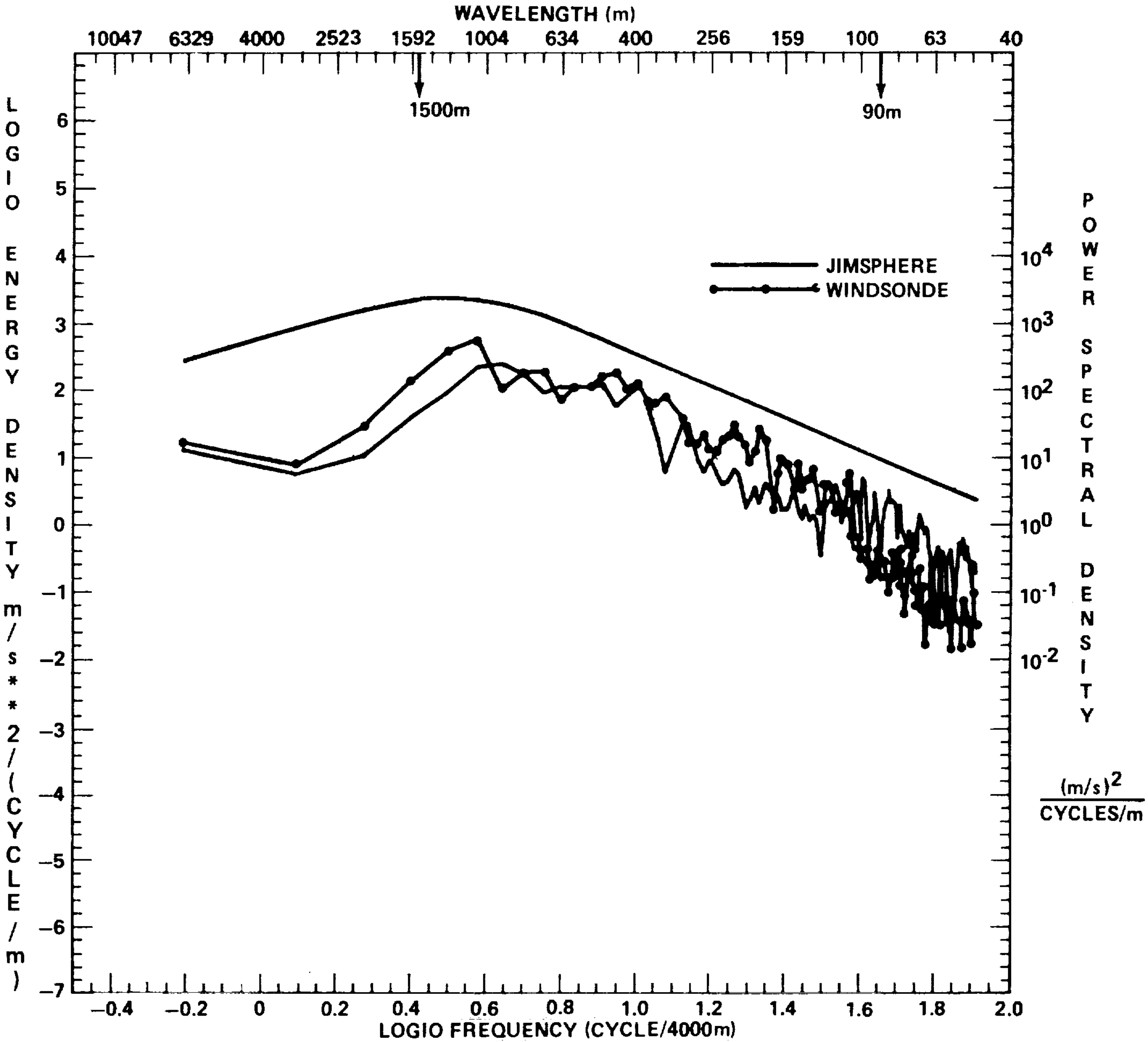

Figure 26. Spectra of Jimsphere and Windsonde, meridional component for STS launch on October 5, 1984, time 0398Z (Jimsphere) and 0403Z (Windsonde) from KSC.

V. SUMMARY REMARKS

It has been shown from a statistical analysis of bivariate parameter differences, that the FPS-16 Radar/Jimsphere and the Meteorological Sounding System (MSS) Windsonde compare favorably in measuring winds aloft. The Jimsphere is used as the standard and the Windsonde as the backup wind sensors in measuring the ascent wind profile during the Space Shuttle launches at Kennedy Space Center, Florida. Computation of the wind statistics from the 64 paired Jimsphere and Windsonde released in support of 14 Space Shuttle launches shows good agreement between the two wind sensors.

The computed difference values in m/s of the mean zonal wind ($\overline{u}$) and mean meridional wind ($\overline{v}$) of the Jimsphere and Windsonde over 500 m intervals from the surface to 16 km shows good agreement between the two wind measurements. The ($\overline{u}$) and ($\overline{v}$) mean differences for the 64 paired observations were 0.16 and 0.22 m/s respectively, while the standard deviations of the mean differences of $\overline{u}$ and $\overline{v}$ were 1.38 and 1.73 m/s respectively.

From the analysis of the buildup and back-off data for scales of distance of 100, 200, 400, 600, 800, 1000, 2000, 3000, and 5000, the windspeed change versus the cumulative percent frequency (CPF), it is shown that Jimsphere and Windsonde compare favorably. For example, the greatest buildup of wind occurred at average altitudes of 10,427 m for the Jimsphere, 10,529 m for the Windsonde, and 10,474 m for the Jimsphere/Windsonde pairs, for all the scale distances. The S.D. of these parameters were 2999, 3029, and 3007 m, less than 50 m difference.

From the Power Spectral Density for the u and v components measured by the Jimsphere and Windsonde, the variance difference range was found to be $\pm$ 0.02 m^2/sec^2. This energy statistic showed that the Jimsphere and Windsonde were good tracers in measuring the winds for loads assessment in the atmosphere during these 14 Space Shuttle launches.

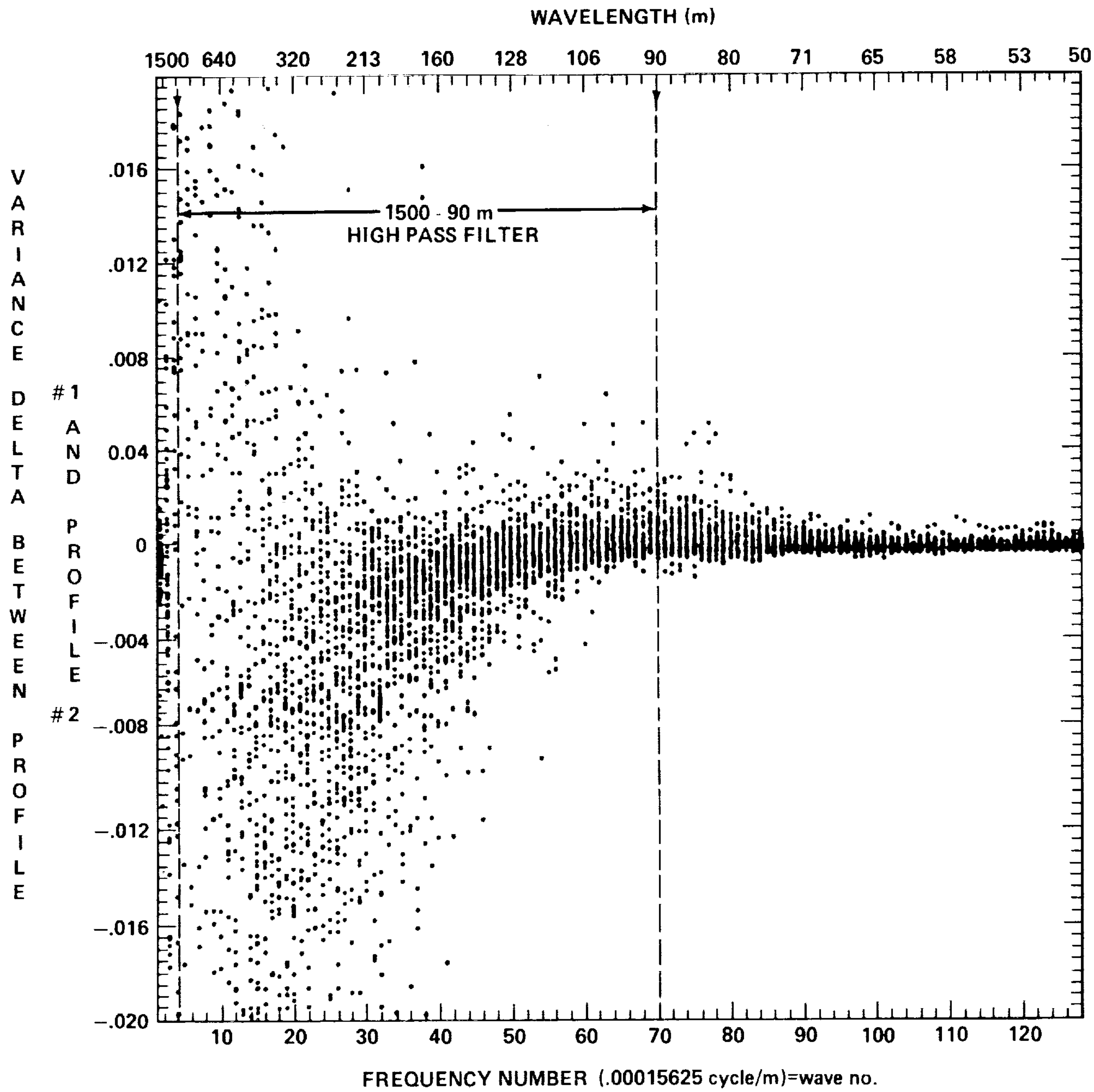

Figure 27. Variance delta between the Jimsphere No. 1 and Windsonde No. 2 u component for 64 pairs of Jimsphere/Windsonde pairs obtained from 14 Space Shuttle launches at KSC.

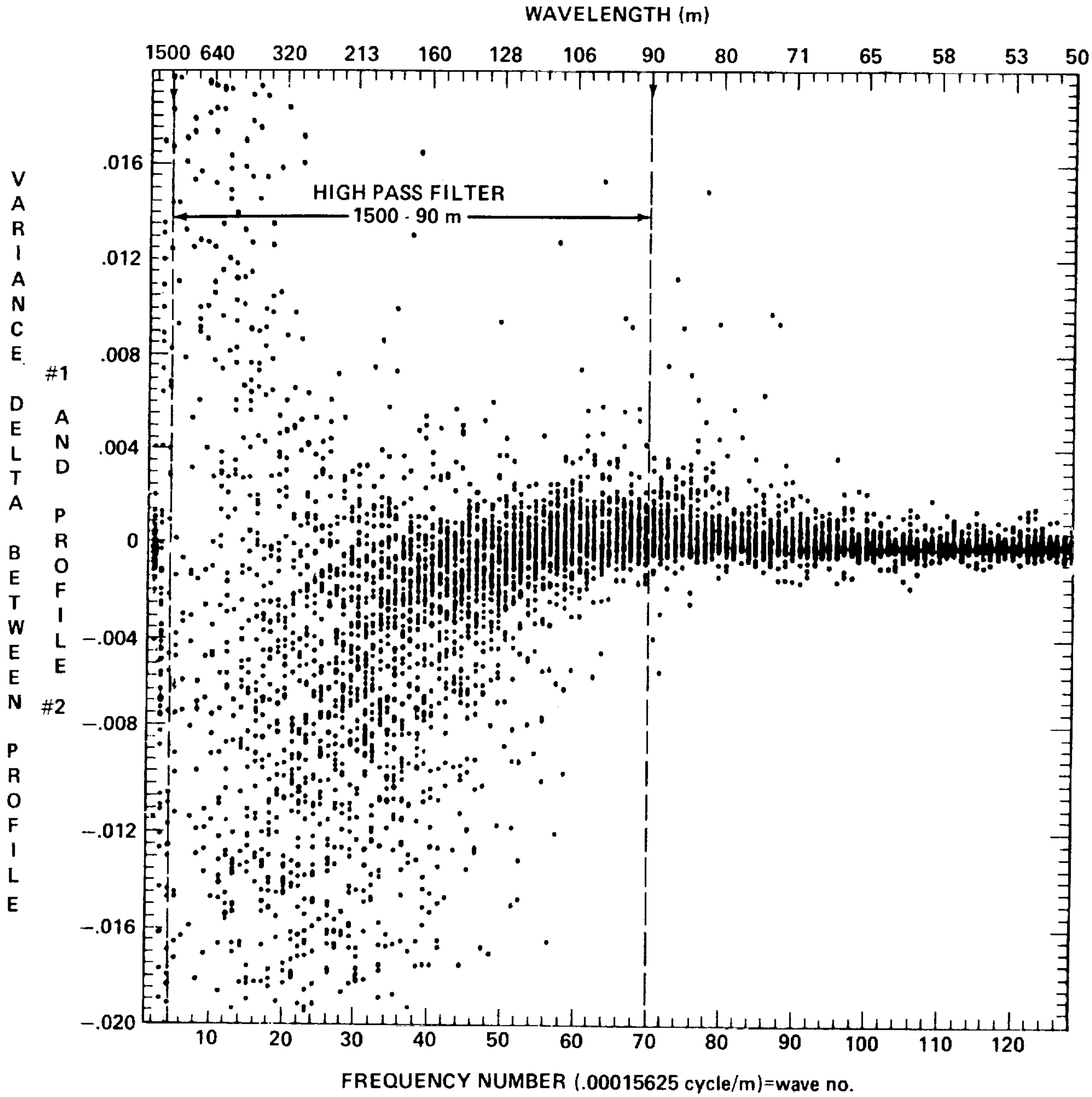

Figure 28. Variance delta between the Jimsphere No. 1 and Windsonde No. 2 v component for 64 pairs of Jimsphere/Windsonde pairs obtained from 14 Space Shuttle launches at KSC.

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APPENDICES A, B, and C

Appendices A, B, and C present a scenario of the Jimsphere and Windsonde balloons being released at KSC in support of STS 61-B, which was launched on November 26, 1985 (1829Z). Appendix A presents the scalar wind speed, wind direction versus altitude for the Jimsphere and Windsonde for T-24 hr., T-7 hr., T-1 hr., T + 2½ hr., and T + 4 hr. For the same times, appendix B illustrates the u and v wind components versus altitude, and appendix C gives the spectra of the u and v components of the Jimsphere and Windsonde.

APPENDIX A

Scalar Wind Speed, Wind Direction Versus Altitude for Jimsphere and Windsonde

Balloon Release Hr (Z)	Jimsphere Time (Z)	Windsonde Time (Z)	Date Mo/Day/Yr
T-24	1829	1826	11/25/85
T-7	1129	1120	11/26/85
T-1	1714	1728	11/26/85
Orbiter Launch 1829Z			11/26/85
T + 2½	2059	2053	11/26/85
T + 4	2214	2229	11/26/85

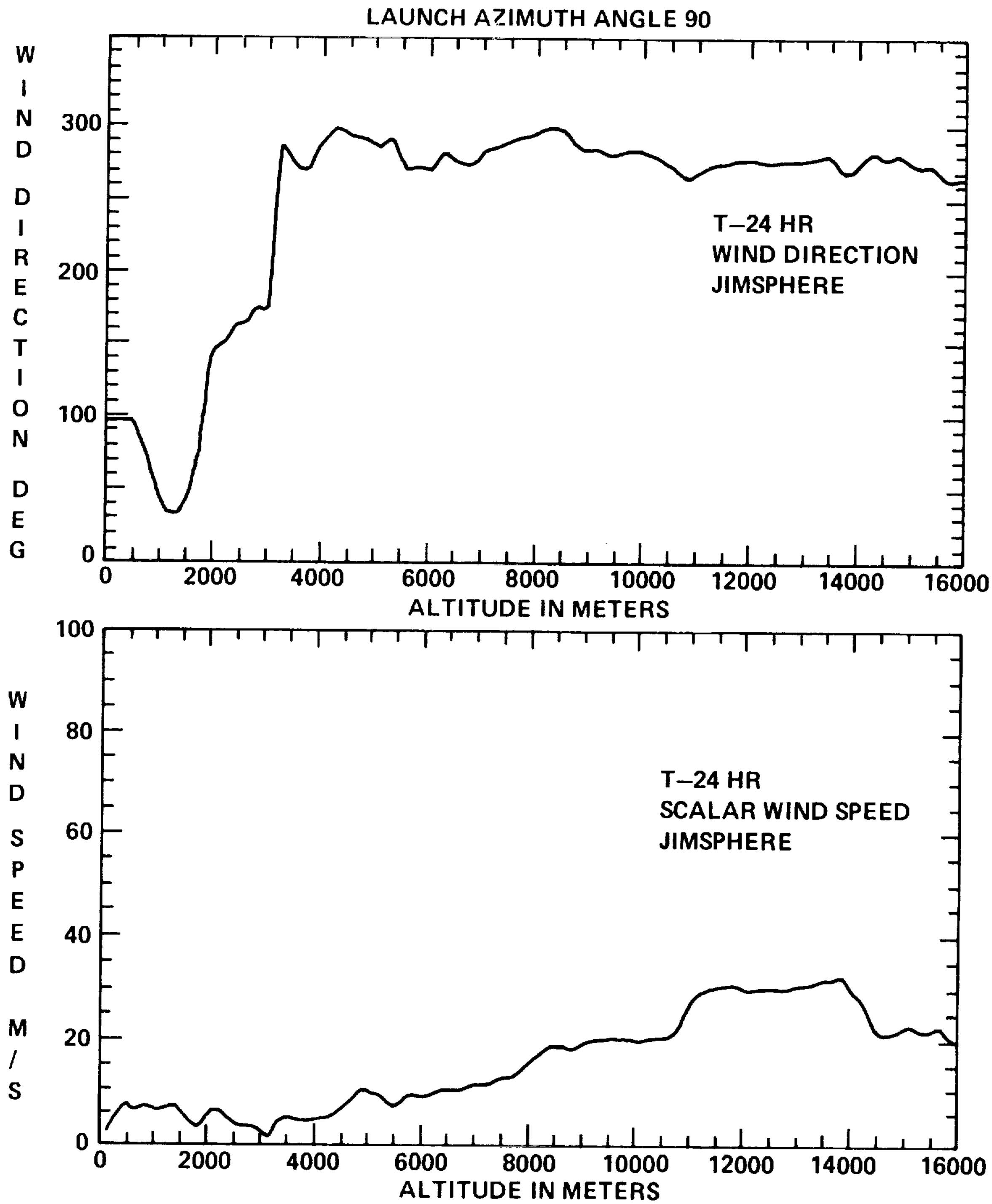

Figure 29. Scalar wind speed and wind direction versus altitude, Jimsphere balloon release at KSC, November 25, 1985 (1829Z).

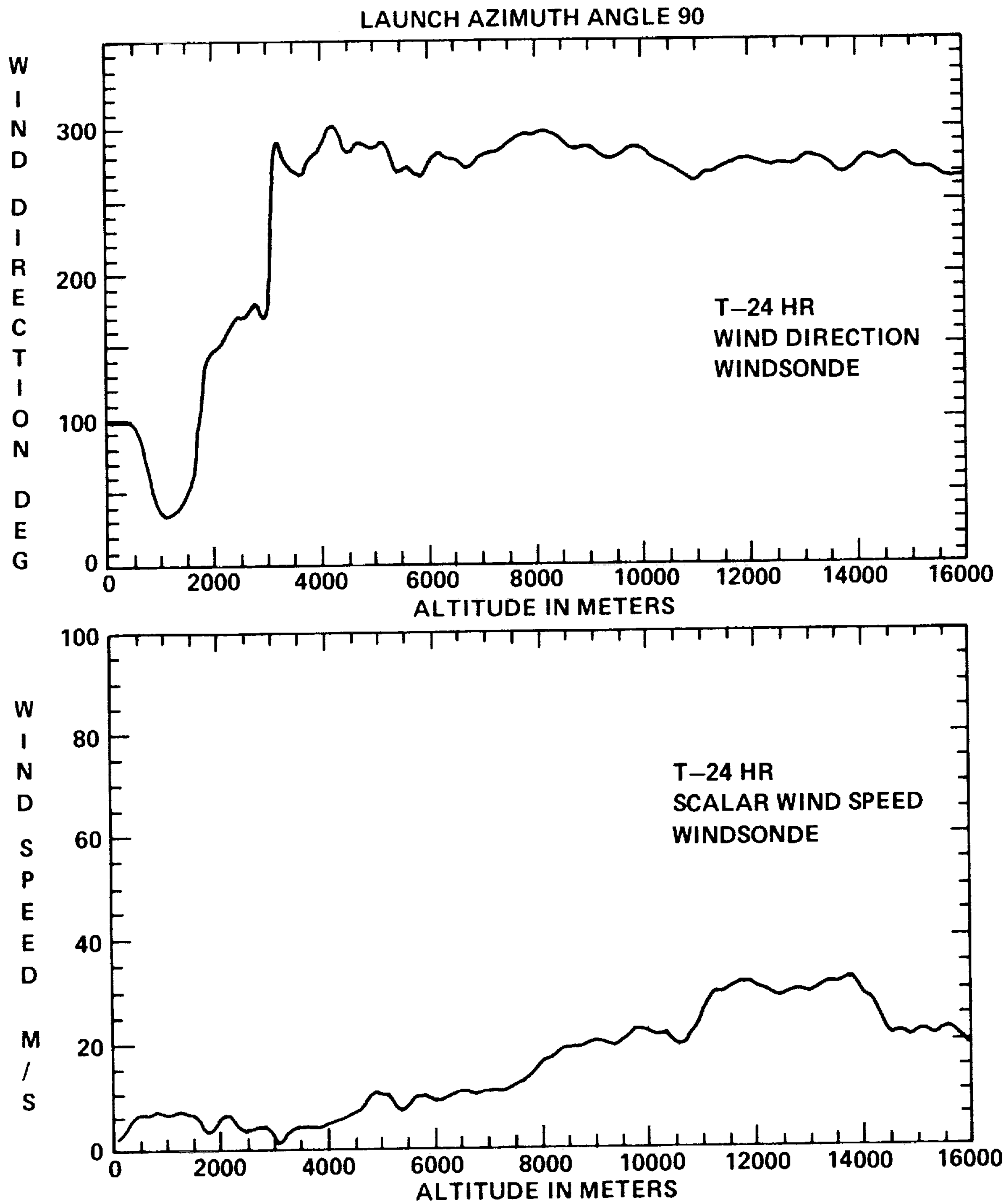

Figure 30. Scalar wind speed and wind direction versus altitude, Windsonde balloon release at KSC, November 25, 1985 (1826Z).

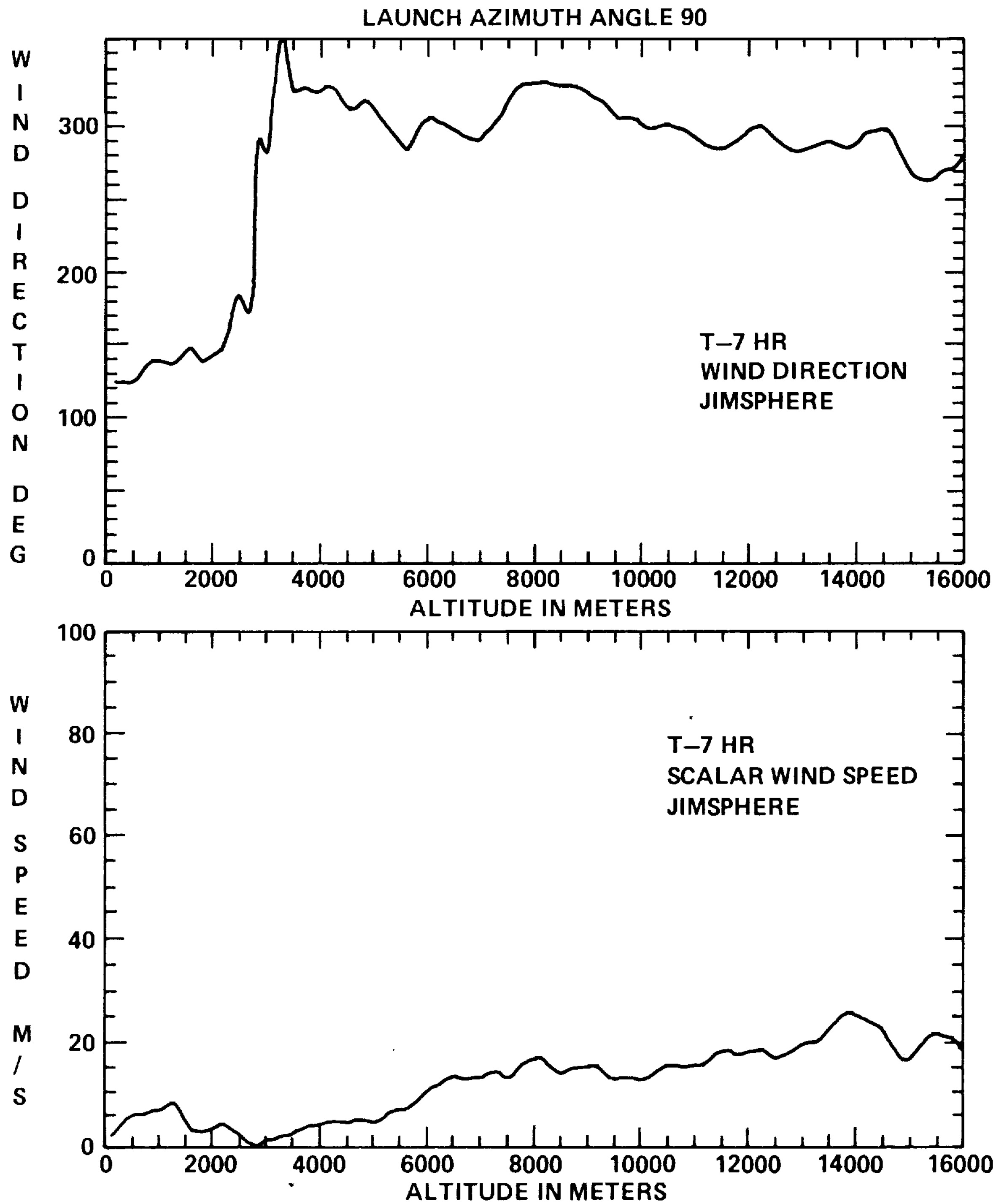

Figure 31. Scalar wind speed and wind direction versus altitude, Jimsphere balloon release at KSC, November 26, 1985 (1129Z).

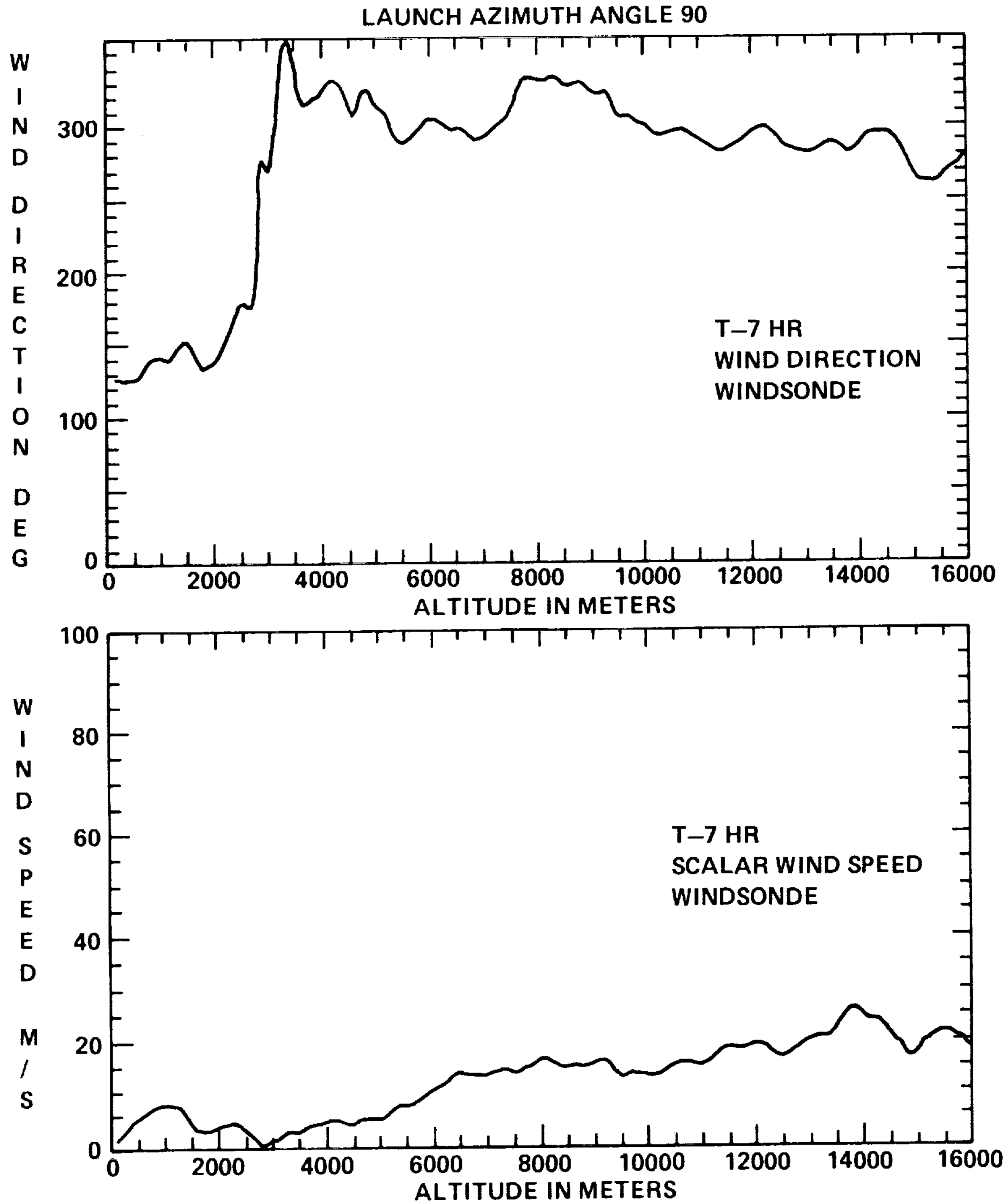

Figure 32. Scalar wind speed and wind direction versus altitude, Windsonde balloon release at KSC, November 26, 1985 (1120Z).

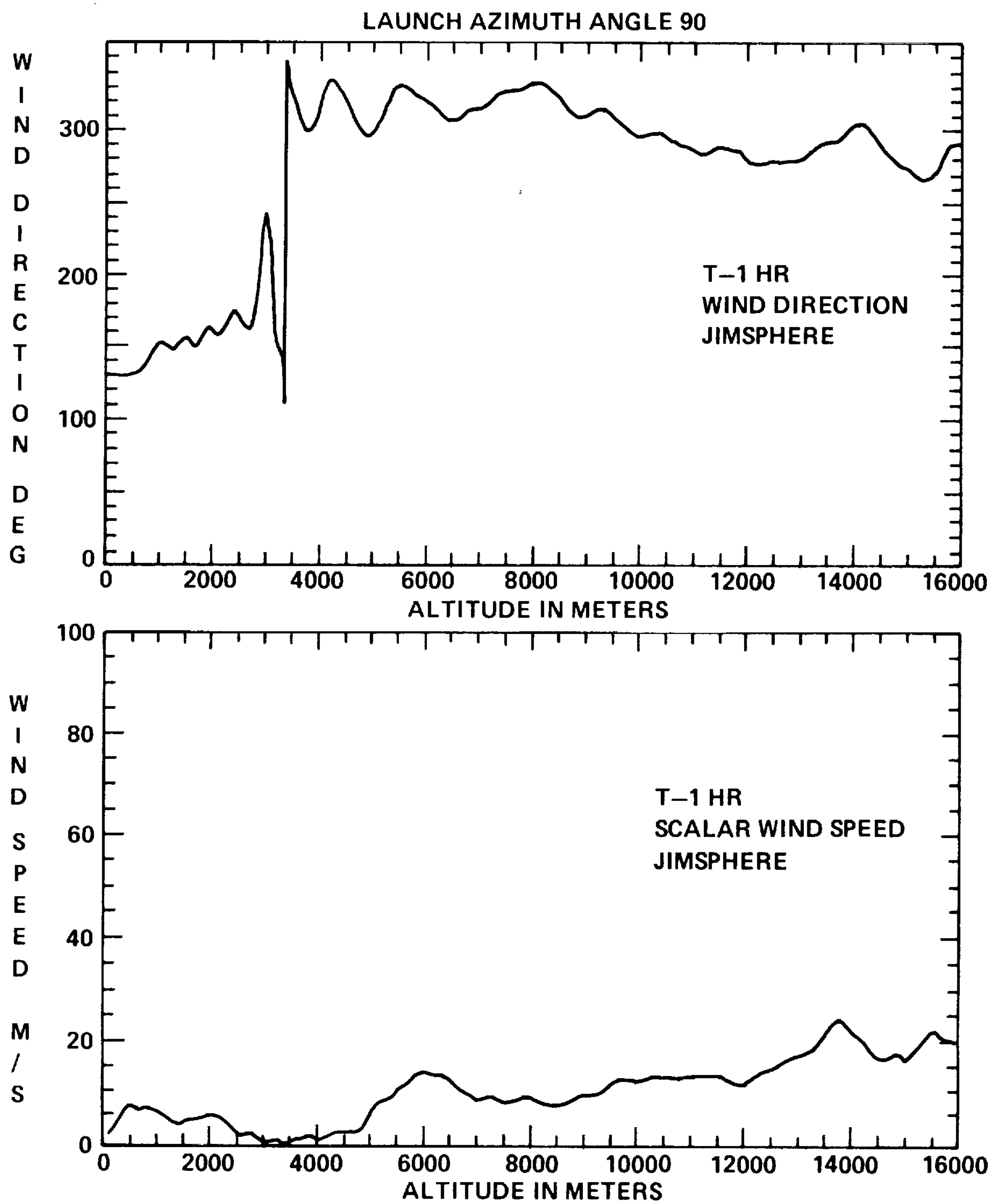

Figure 33. Scalar wind speed and wind direction versus altitude, Jimsphere balloon release at KSC, November 26, 1985 (1714Z).

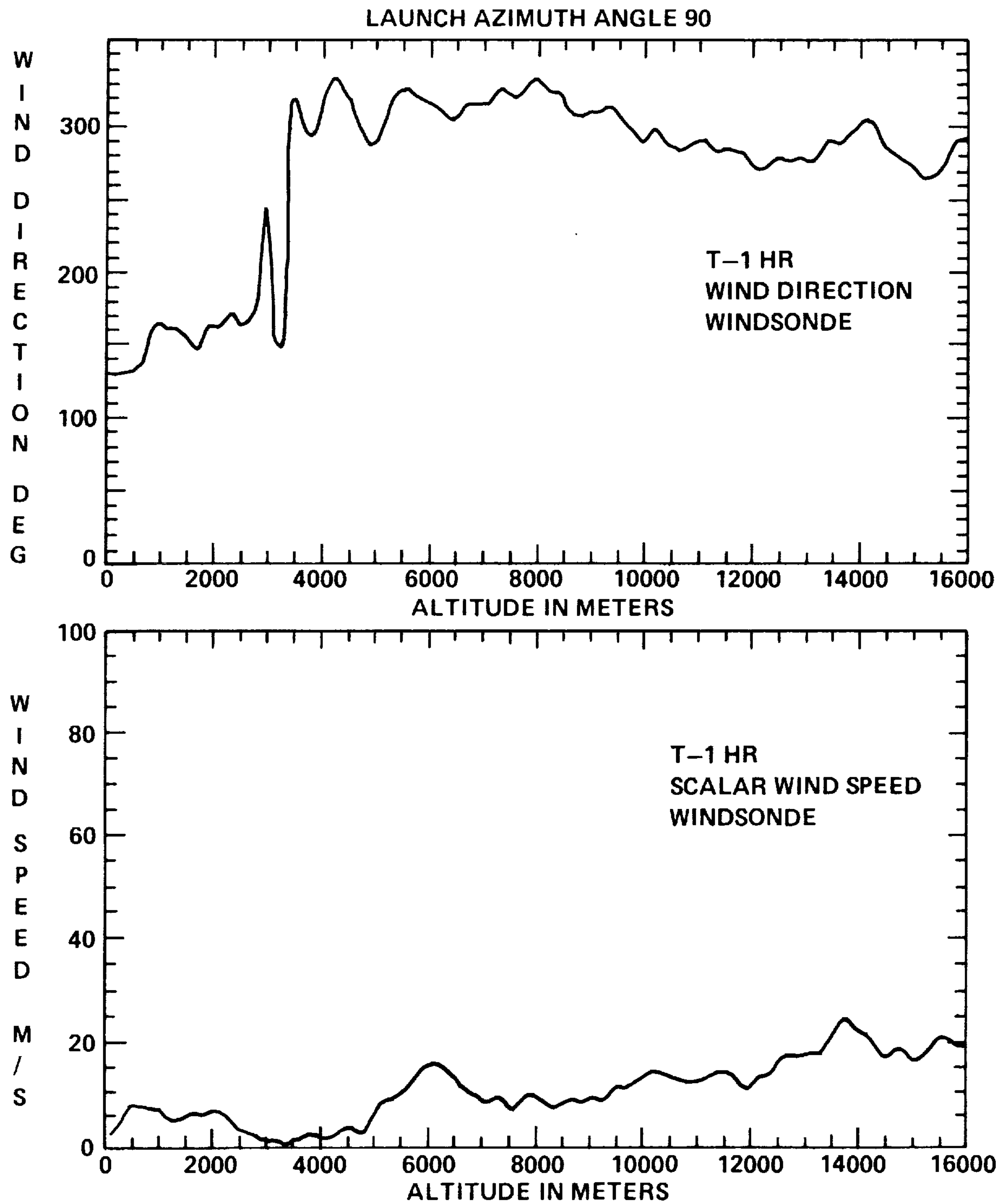

Figure 34. Scalar wind speed and wind direction versus altitude, Windsonde balloon release at KSC, November 26, 1985 (1728Z).

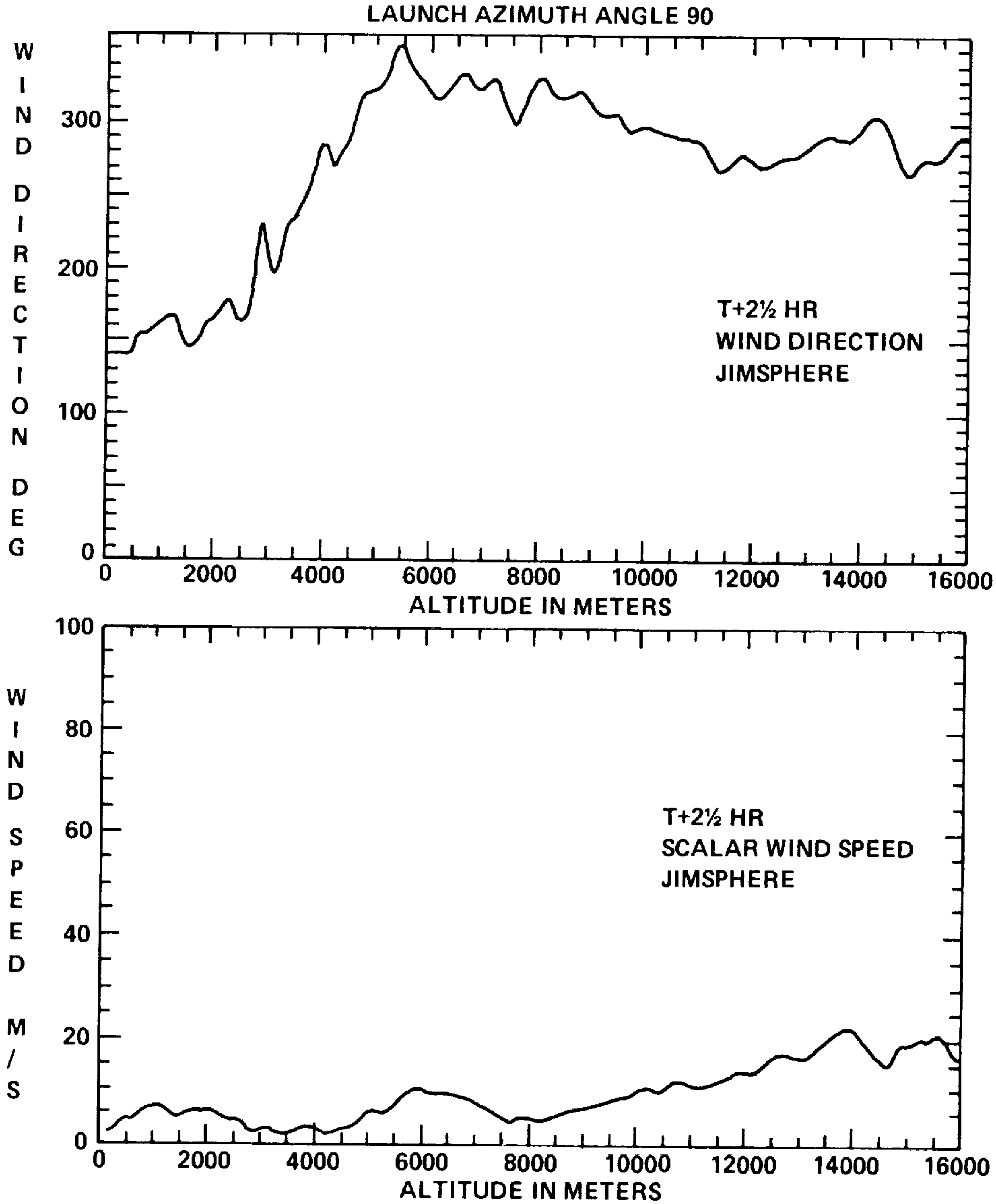

Figure 35. Scalar wind speed and wind direction versus altitude, Jimsphere balloon release at KSC, November 26, 1985 (2059Z).

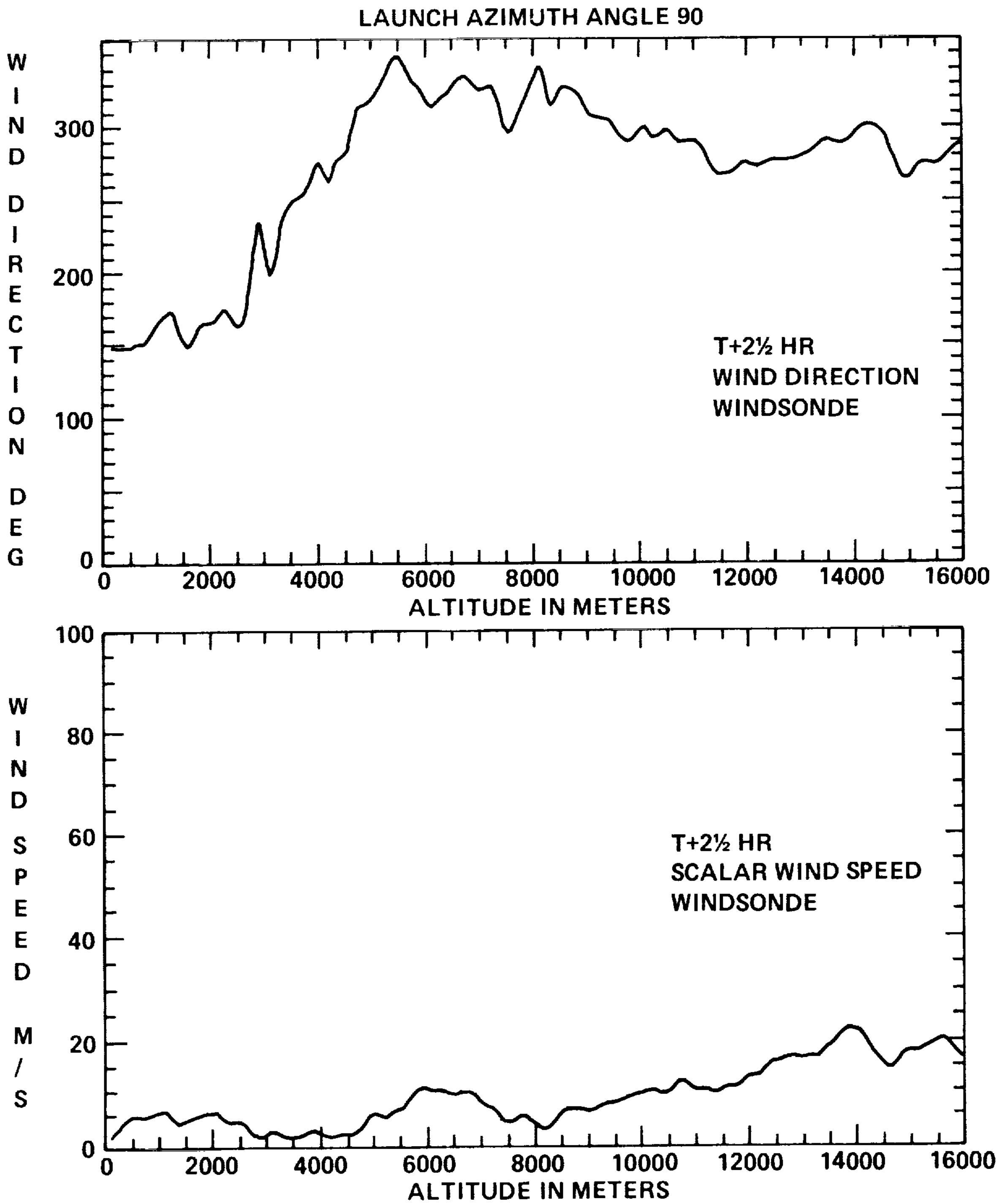

Figure 36. Scalar wind speed and wind direction versus altitude, Windsonde balloon release at KSC, November 26, 1985 (2053Z).

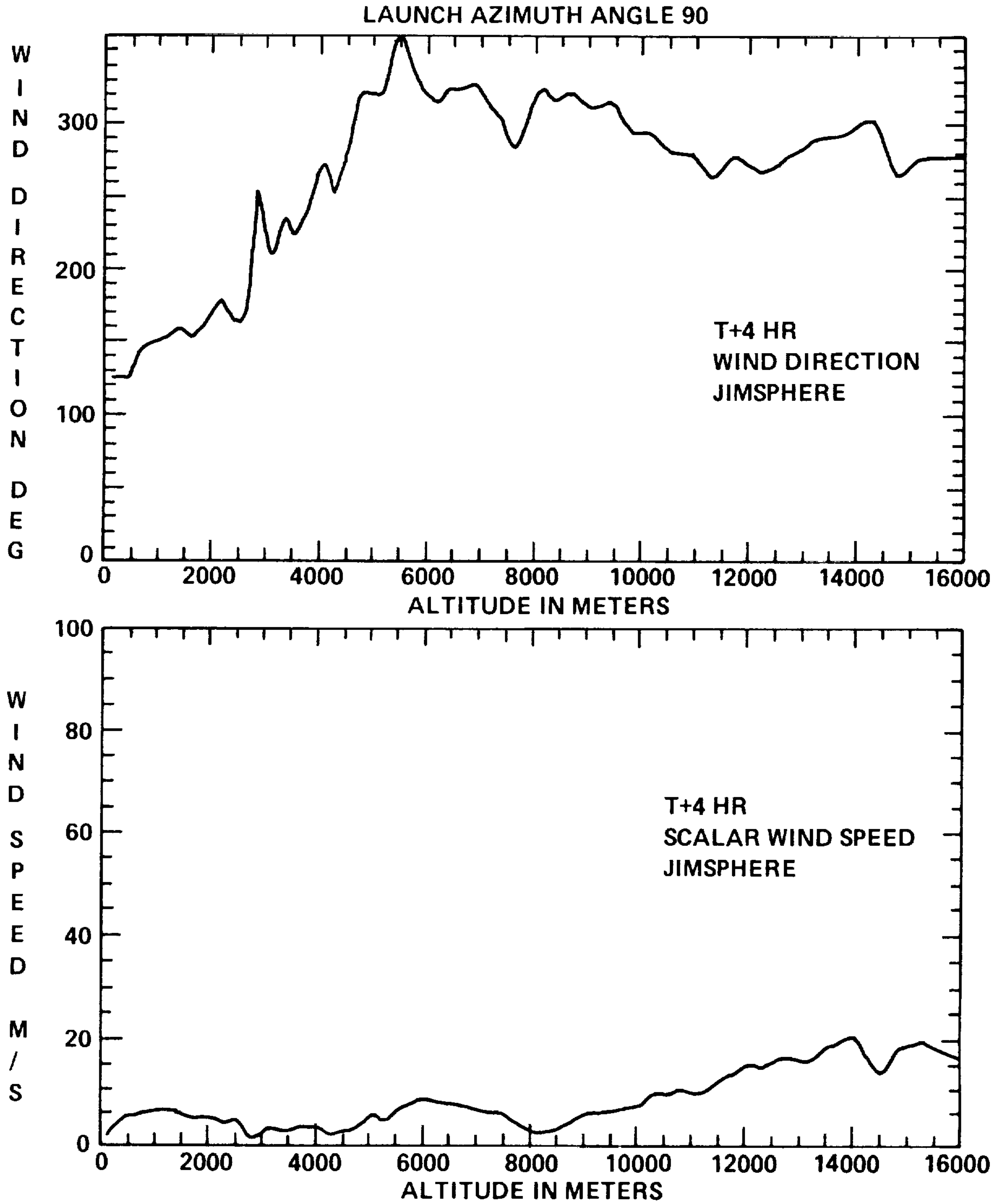

Figure 37. Scalar wind speed and wind direction versus altitude, Jimsphere balloon release at KSC, November 26, 1985 (2214Z).

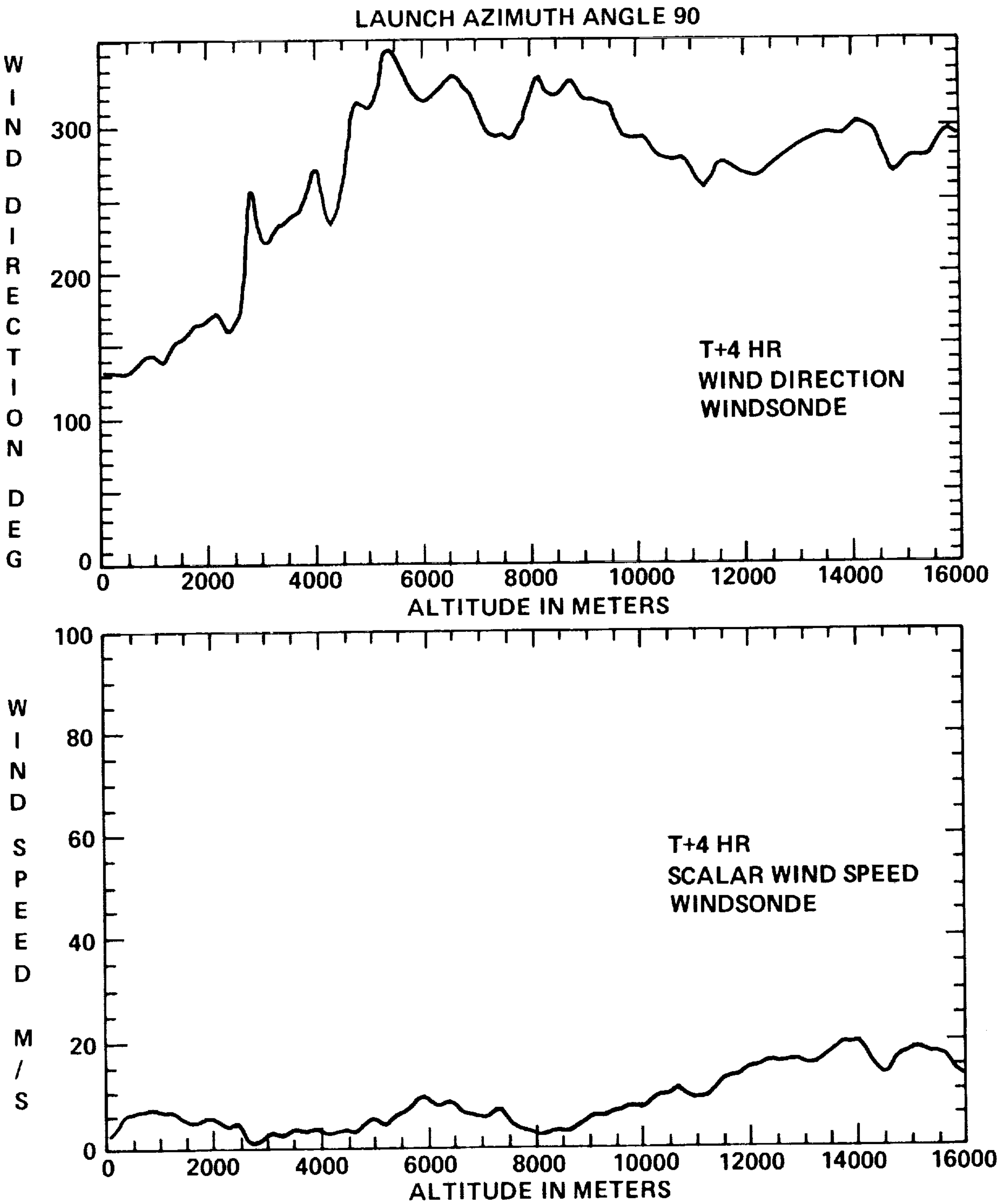

Figure 38. Scalar wind speed and wind direction versus altitude, Windsonde balloon release at KSC, November 26, 1985 (2229Z).

APPENDIX B

U and V Wind Components Versus Altitude for Jimsphere and Windsonde

Balloon Release Hr. (Z)	Jimsphere Time (Z)	Windsonde Time (Z)	Date Mo/Day/Yr
T-24	1829	1826	11/25/85
T-7	1129	1120	11/26/85
T-1	1714	1728	11/26/85
Orbiter Launch 1829Z			11/26/85
T+2½	2059	2053	11/26/85
T+4	2214	2229	11/26/85

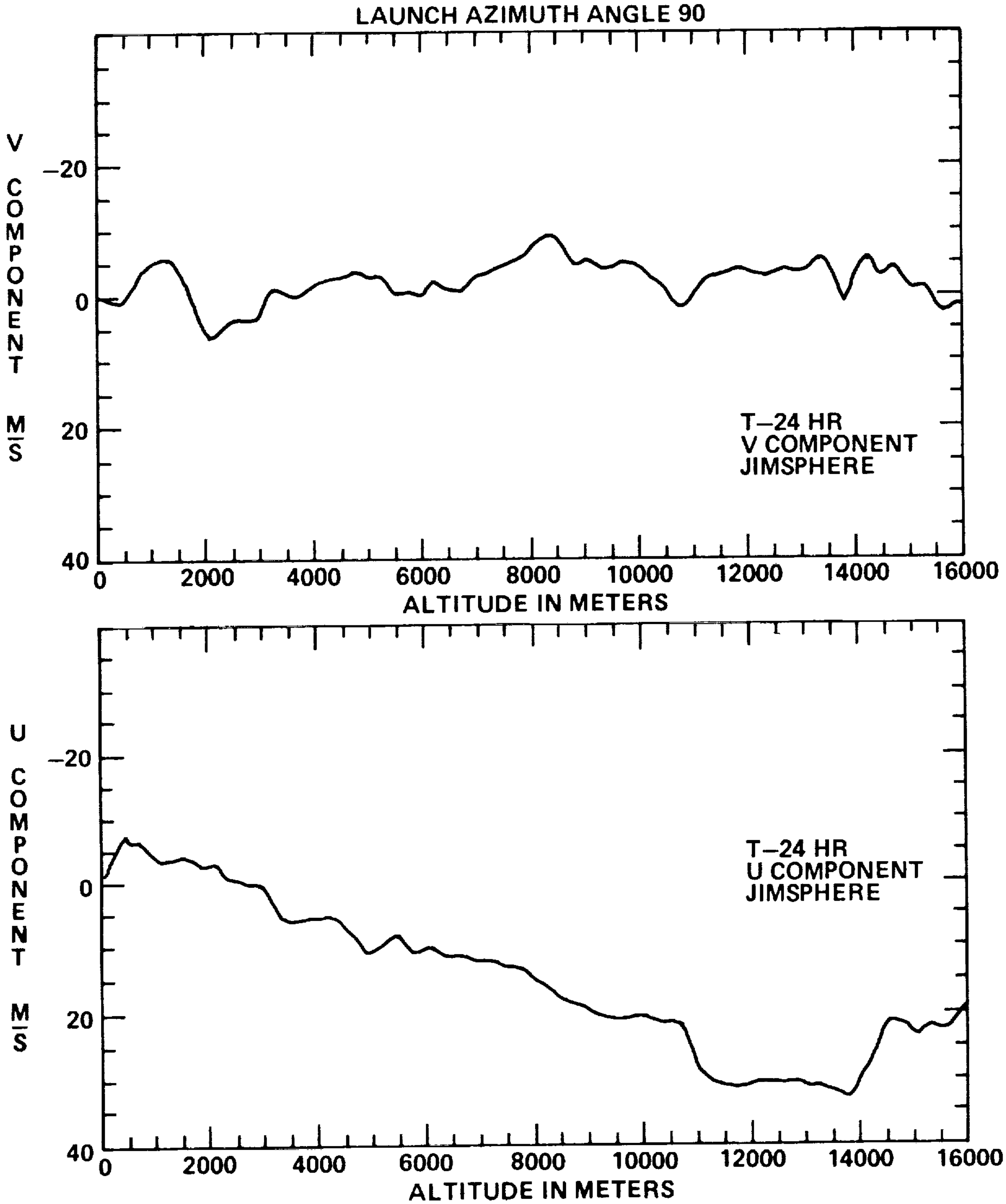

Figure 39. U and V wind components versus altitude, Jimsphere balloon release at KSC, November 25, 1985 (1829Z).

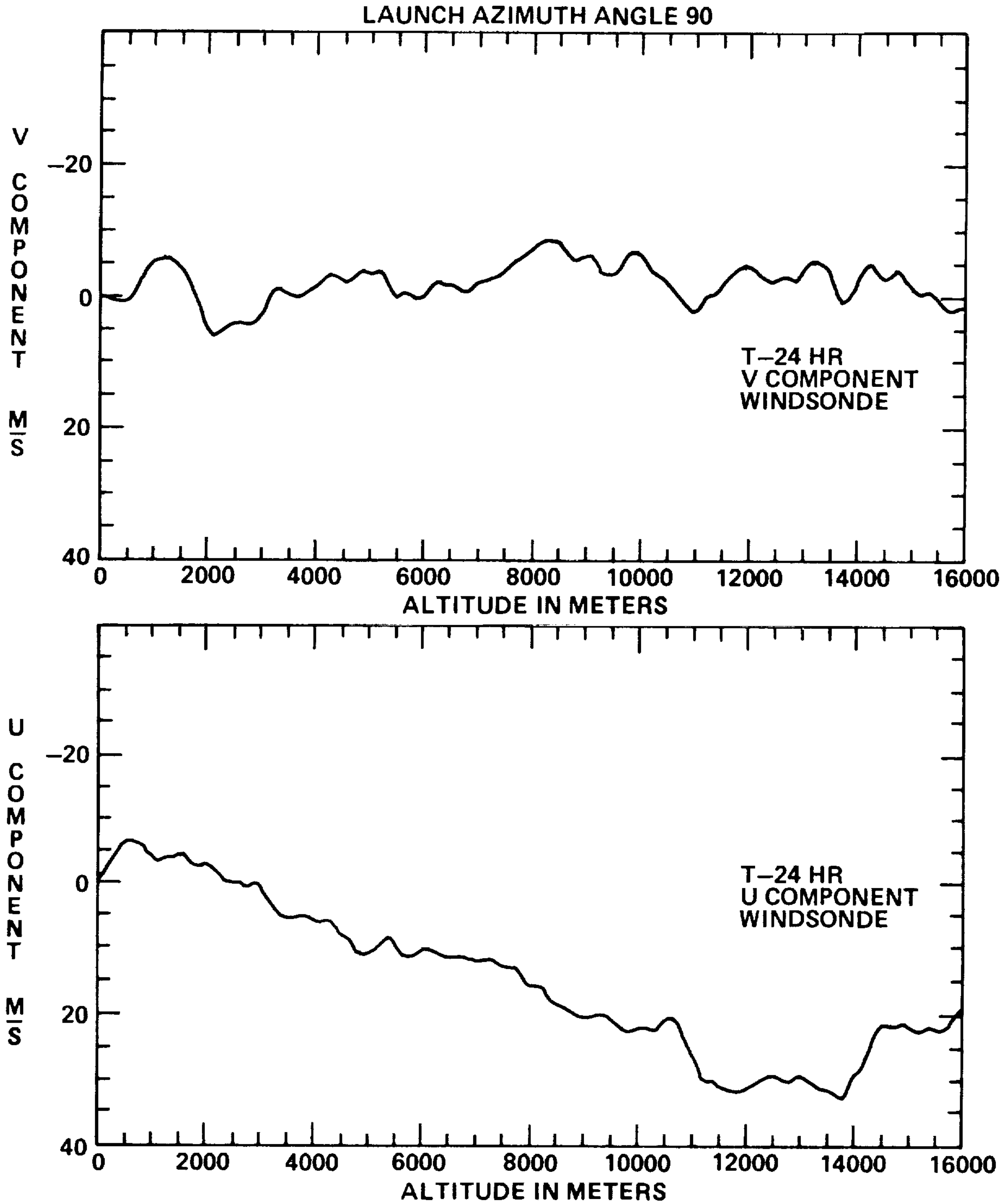

Figure 40. U and V wind components versus altitude, Windsonde balloon release at KSC, November 25, 1985 (1826Z).

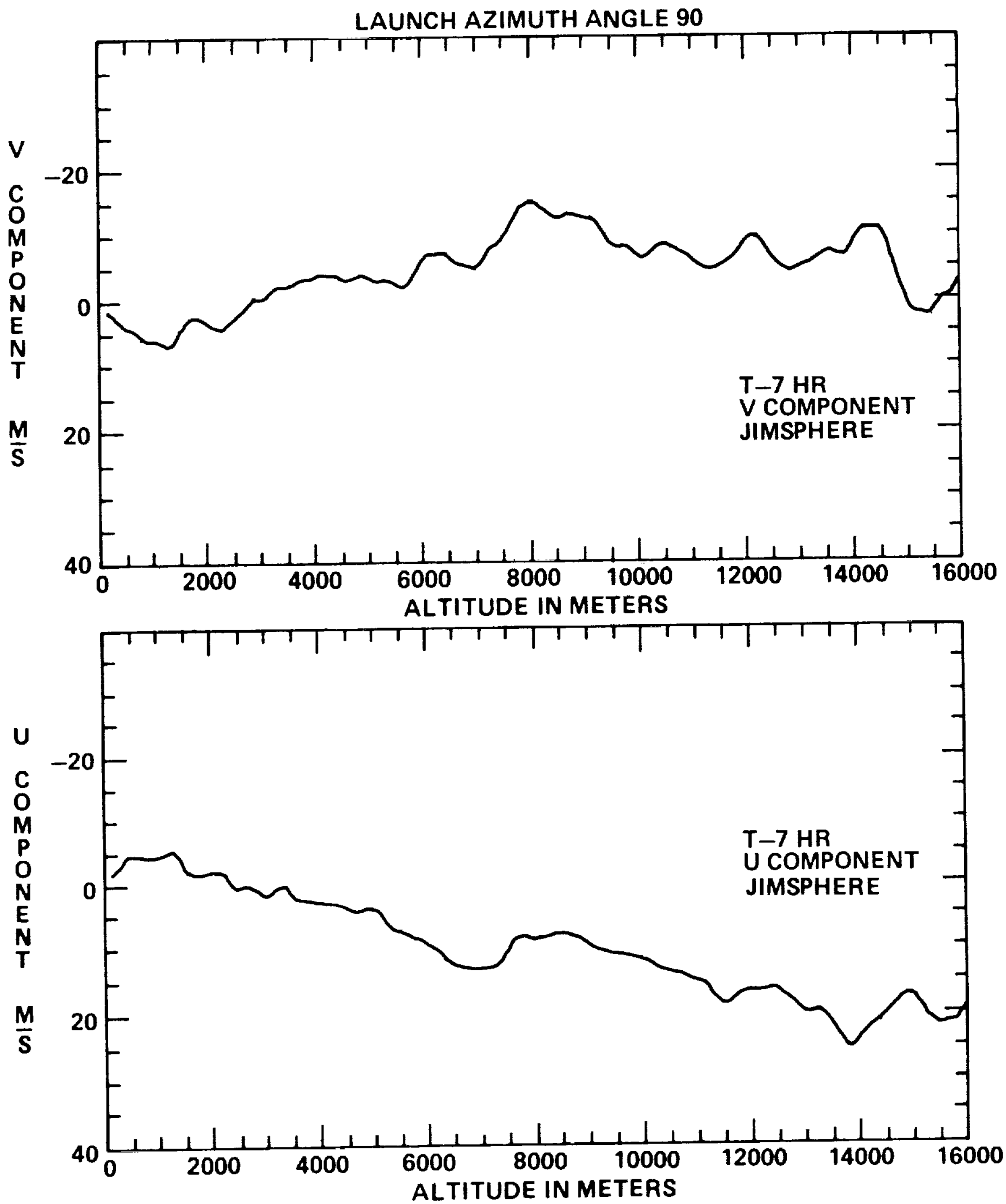

Figure 41. U and V wind components versus altitude, Jimsphere balloon release at KSC, November 26, 1985 (1129Z).

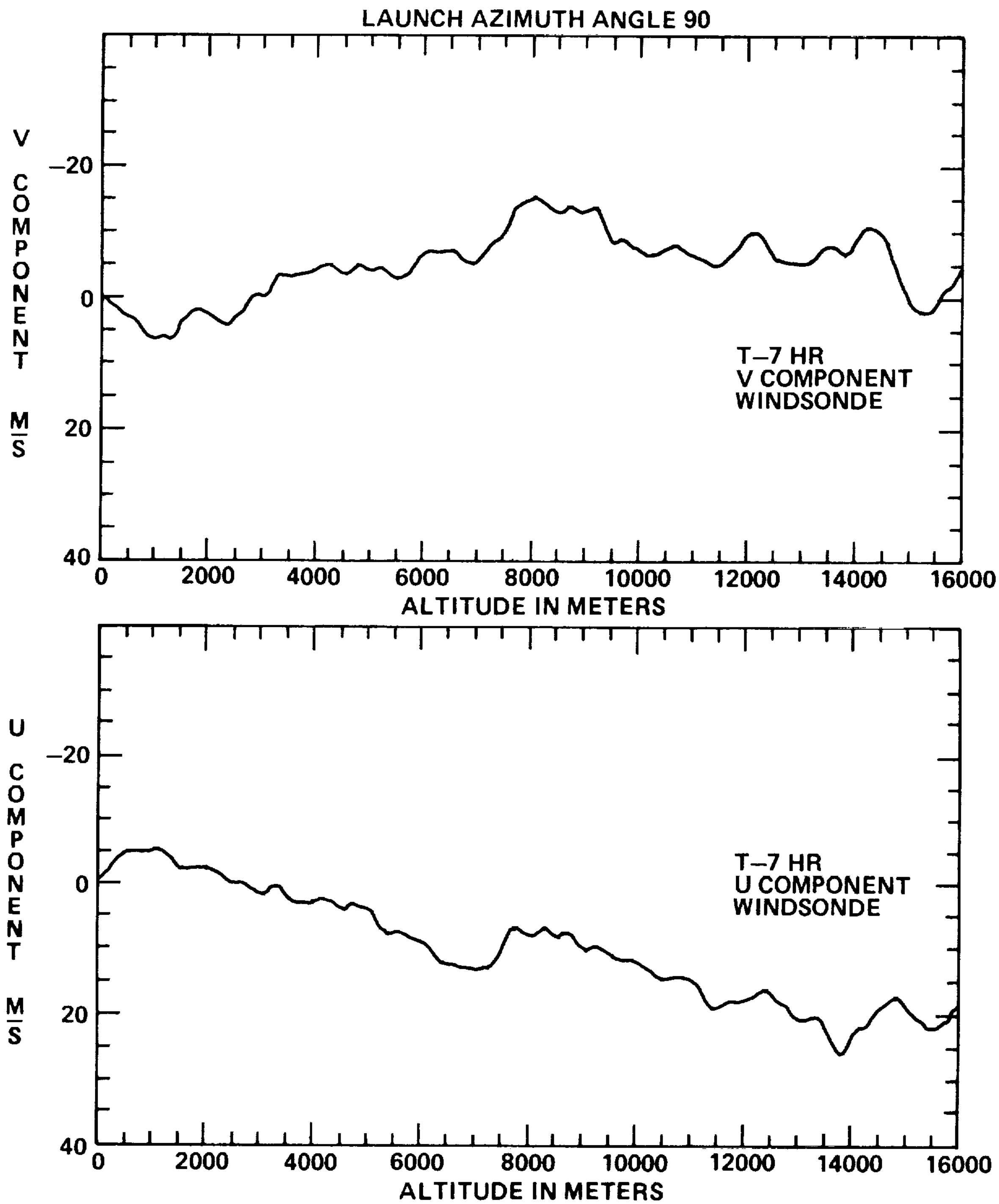

Figure 42. U and V wind components versus altitude, Windsonde balloon release at KSC, November 26, 1985 (1120Z).

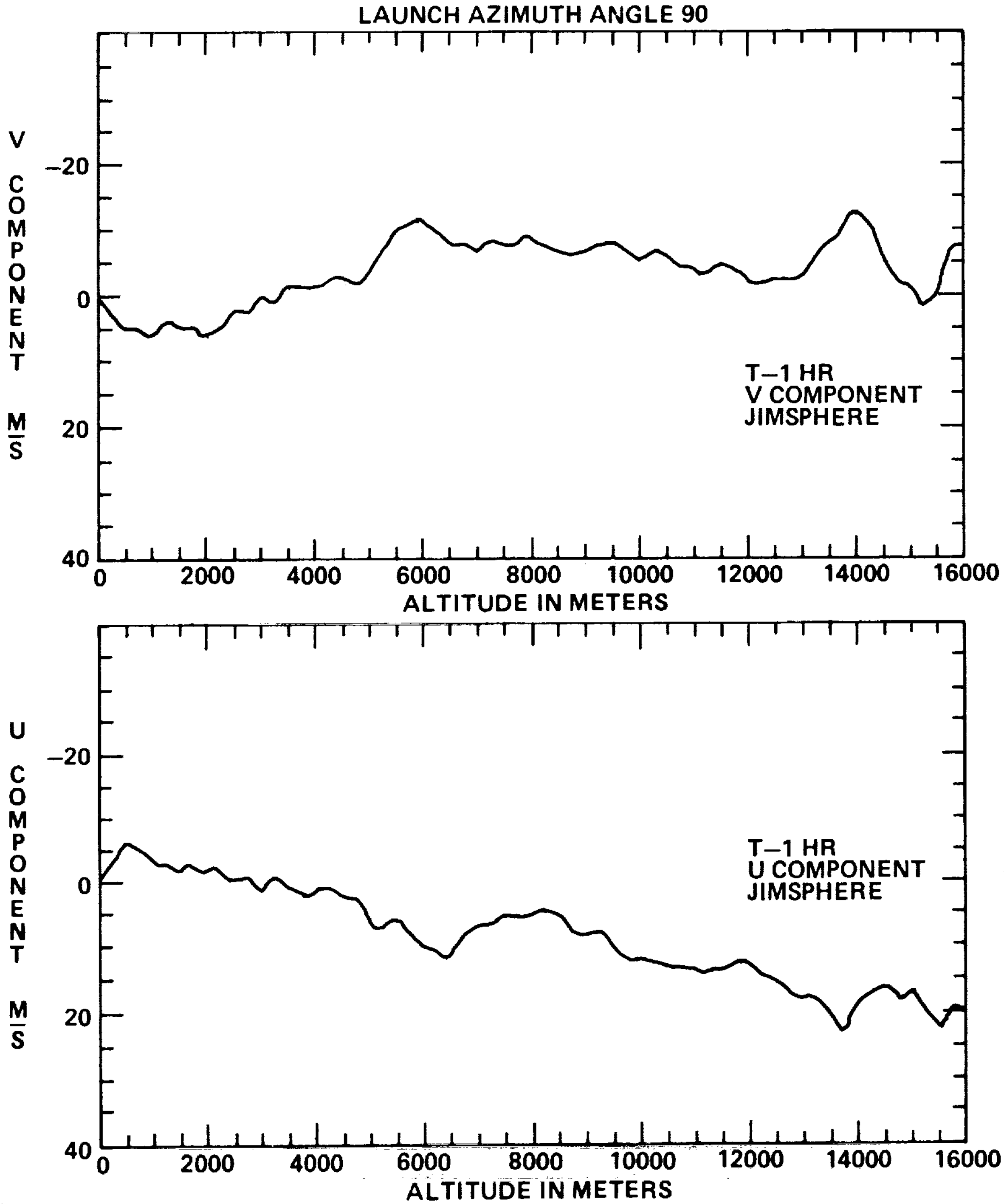

Figure 43. U and V wind components versus altitude, Jimsphere balloon release at KSC, November 26, 1985 (1714Z).

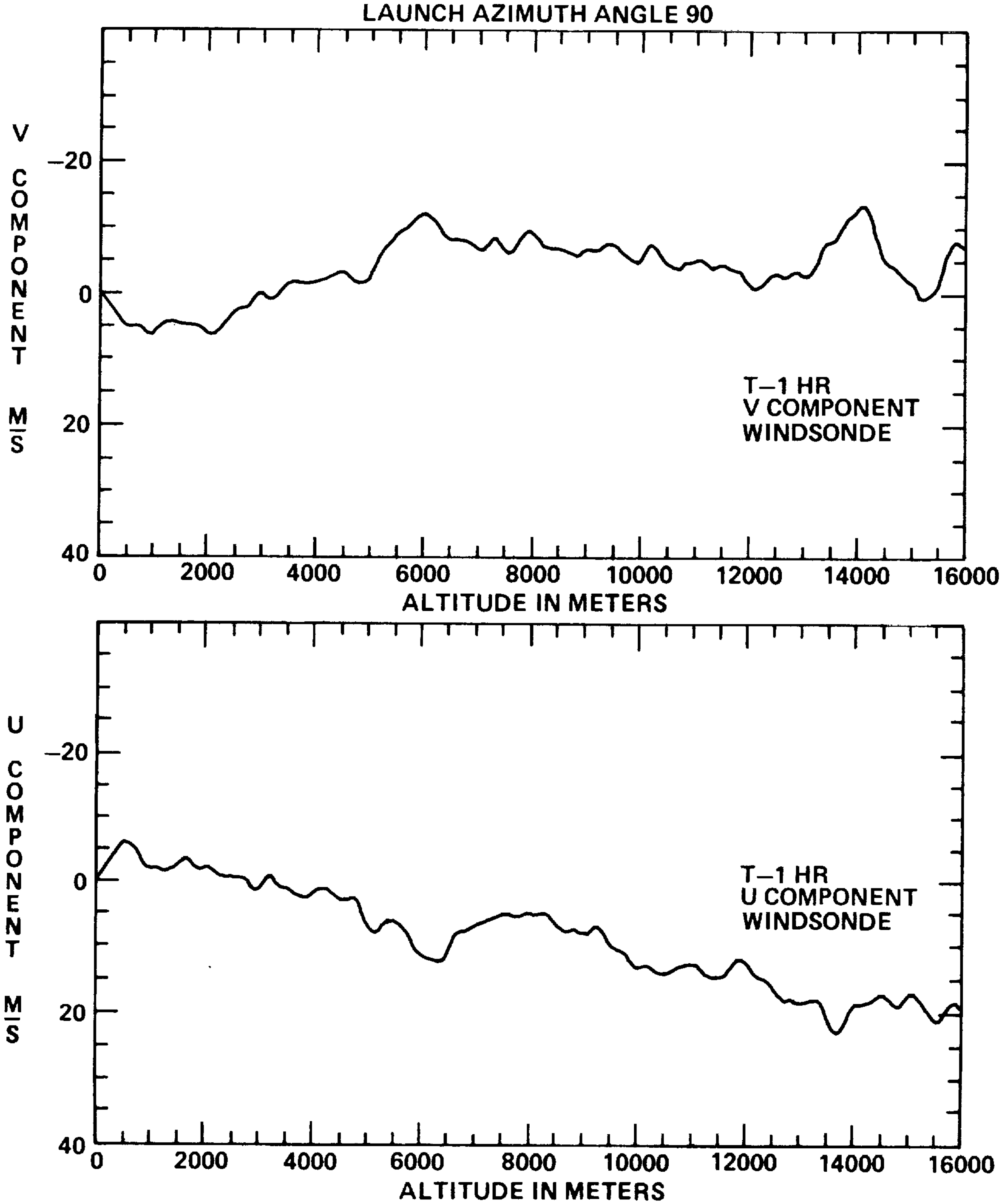

Figure 44. U and V wind components versus altitude, Windsonde balloon release at KSC, November 26, 1985 (1728Z).

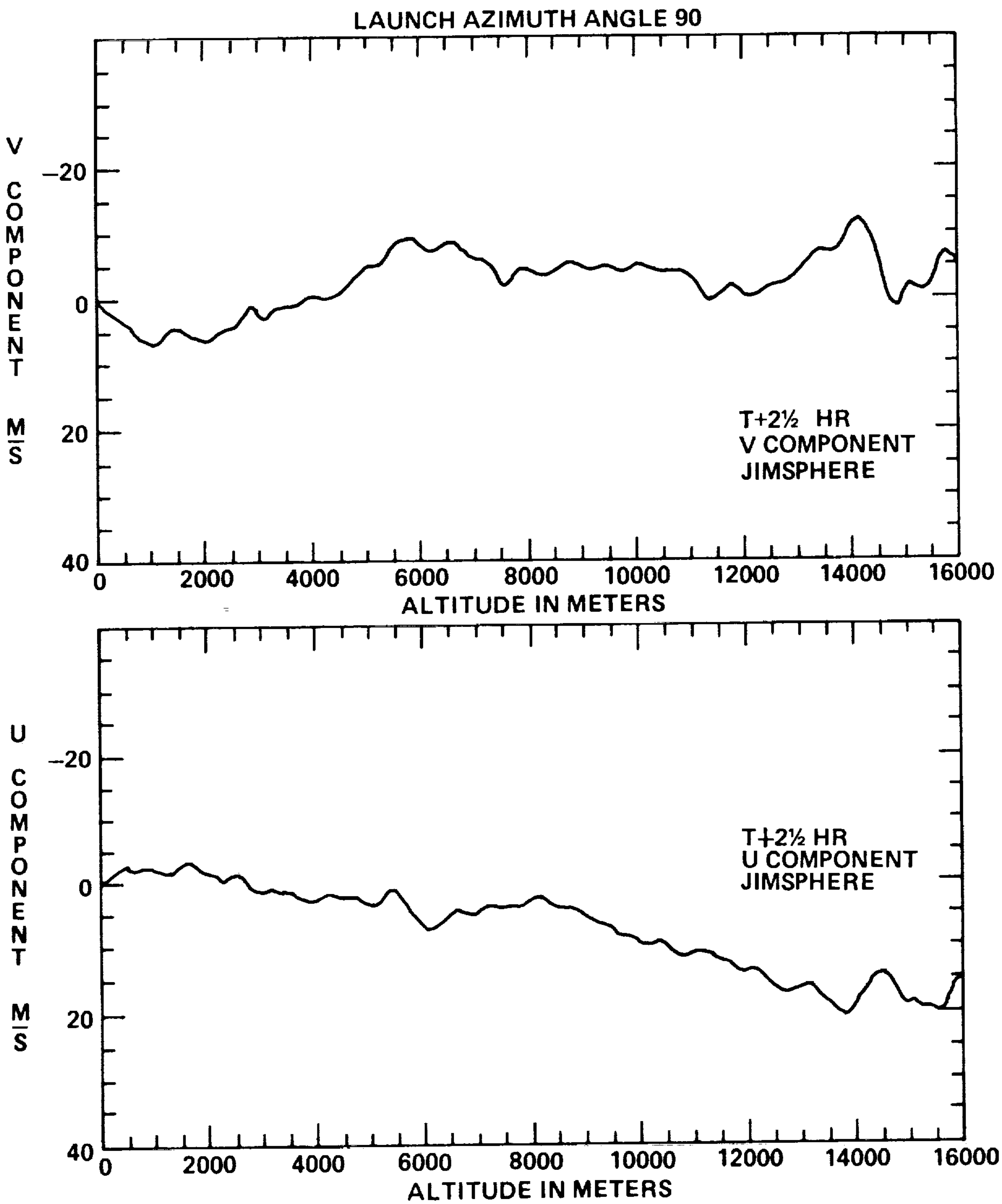

Figure 45. U and V wind components versus altitude, Jimsphere balloon release at KSC, November 26, 1985 (2059Z).

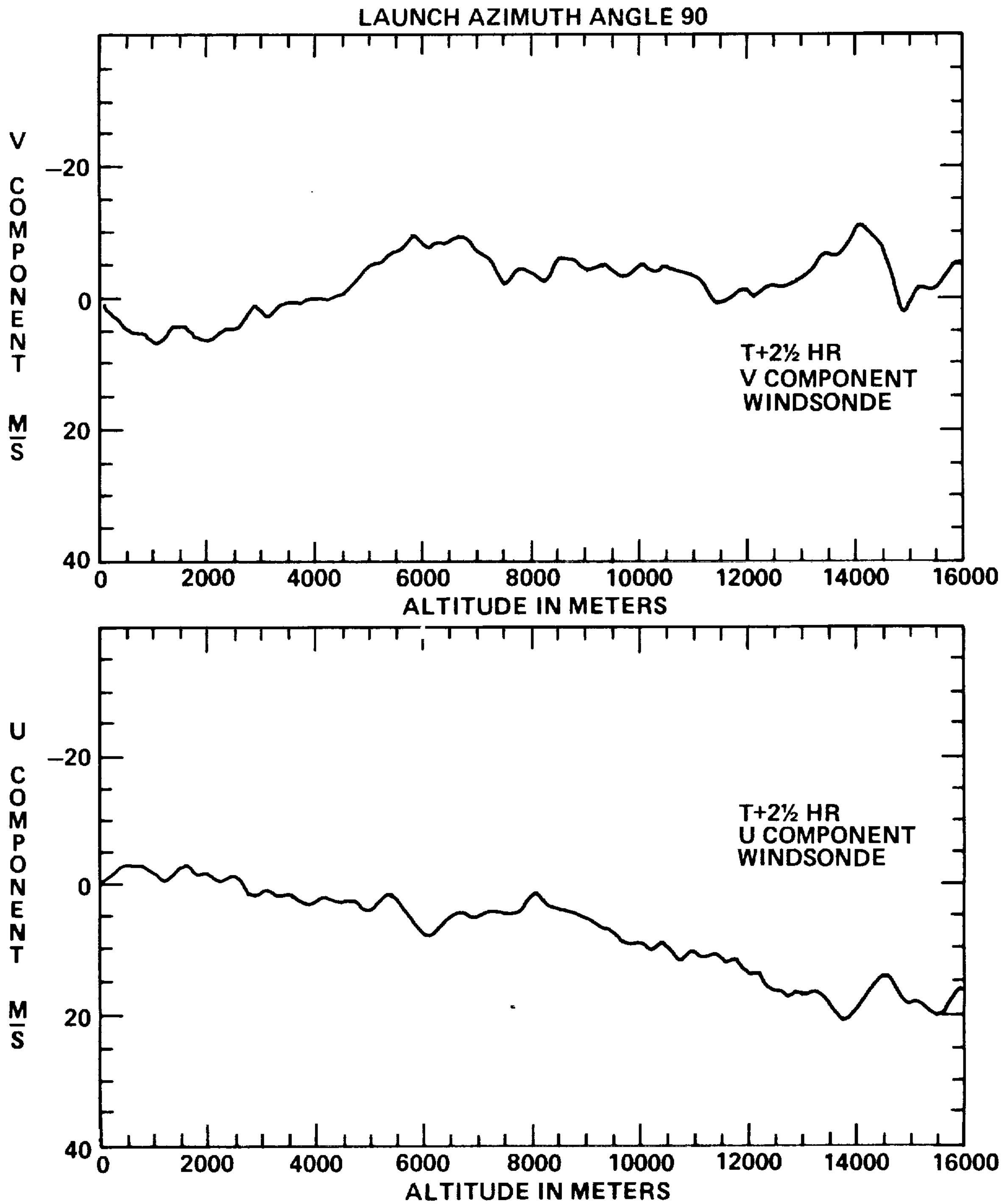

Figure 46. U and V wind components versus altitude, Windsonde balloon release at KSC, November 26, 1985 (2053Z).

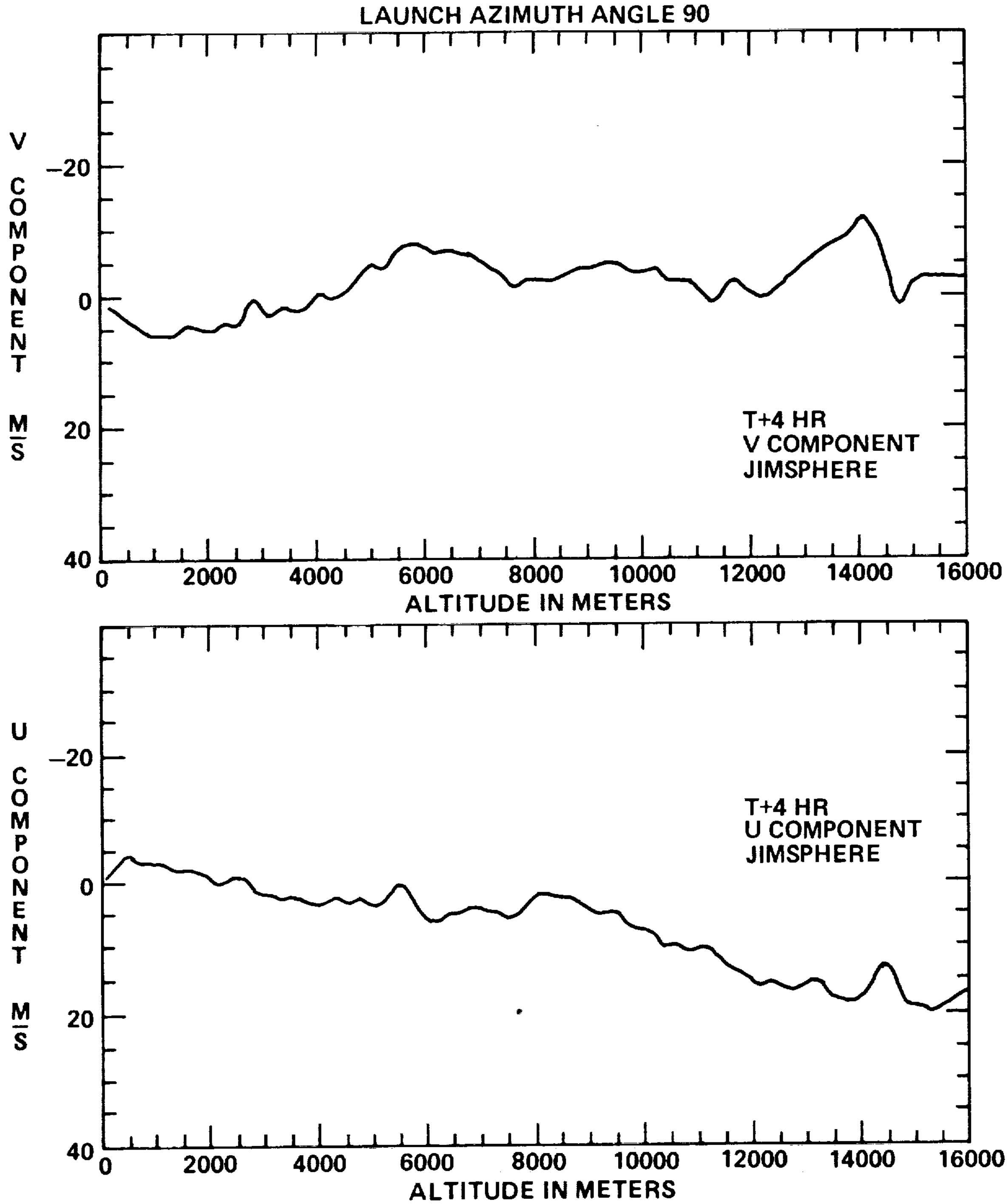

Figure 47. U and V wind components versus altitude, Jimsphere balloon release at KSC, November 26, 1985 (2214Z).

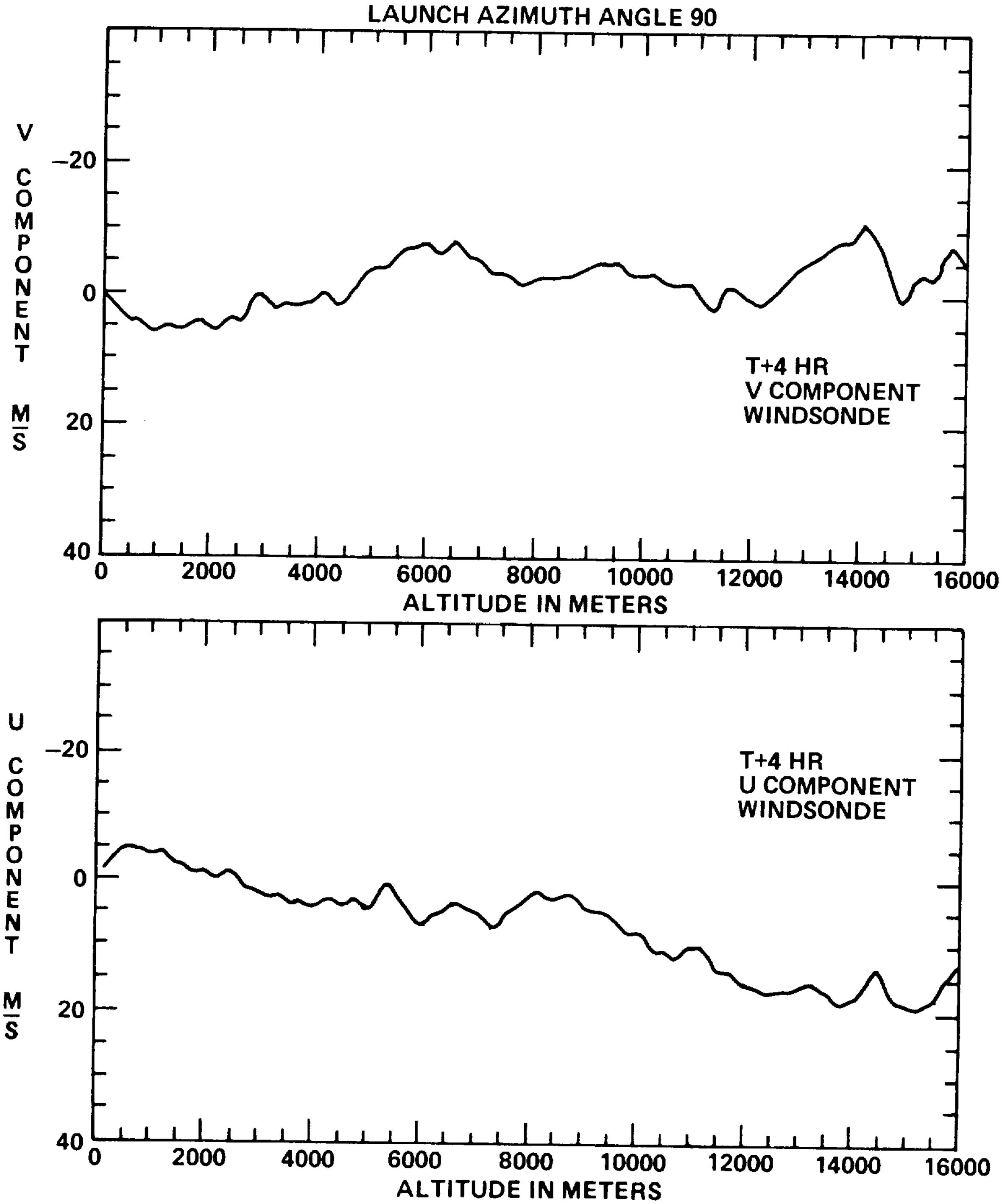

Figure 48. U and V wind components versus altitude, Windsonde balloon release at KSC, November 26, 1985 (2229Z).

APPENDIX C

Spectra of U and V Wind Components for Jimsphere and Windsonde

Balloon Release Hr. (Z)	Jimsphere Time (Z)	Windsonde Time (Z)	Date Mo/Day/Yr
T-24	1829	1826	11/25/85
T-7	1129	1120	11/26/85
T-1	1714	1728	11/26/85
Orbiter Launch 1829Z			11/26/85
T + 2½	2059	2053	11/26/85
T + 4	2214	2229	11/26/85

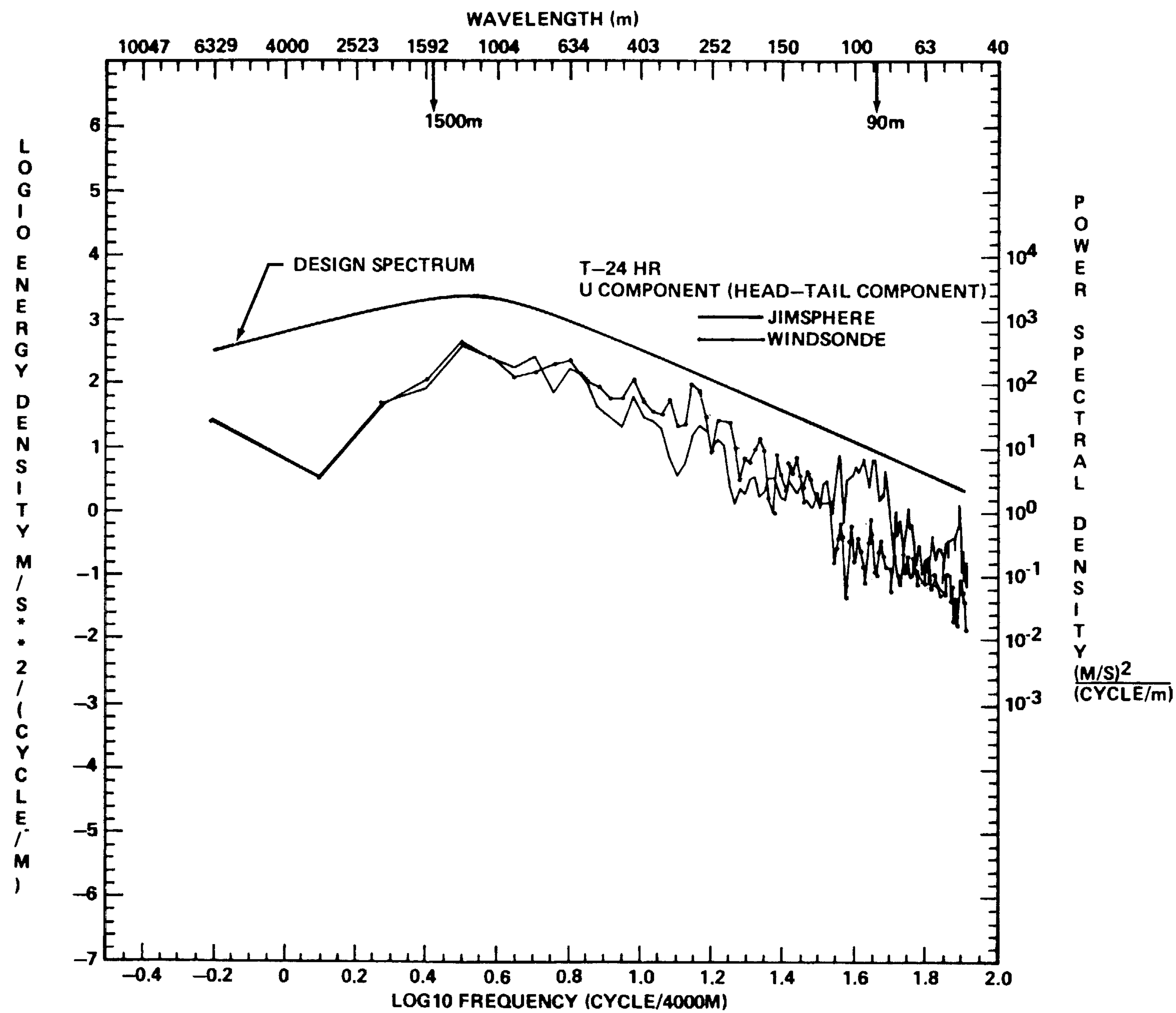

Figure 49. T-24 spectra of U component of Jimsphere (1829Z, November 25, 1985) and Windsonde (1826Z, November 25, 1985) for STS launch on November 26, 1985 (1829Z) at KSC.

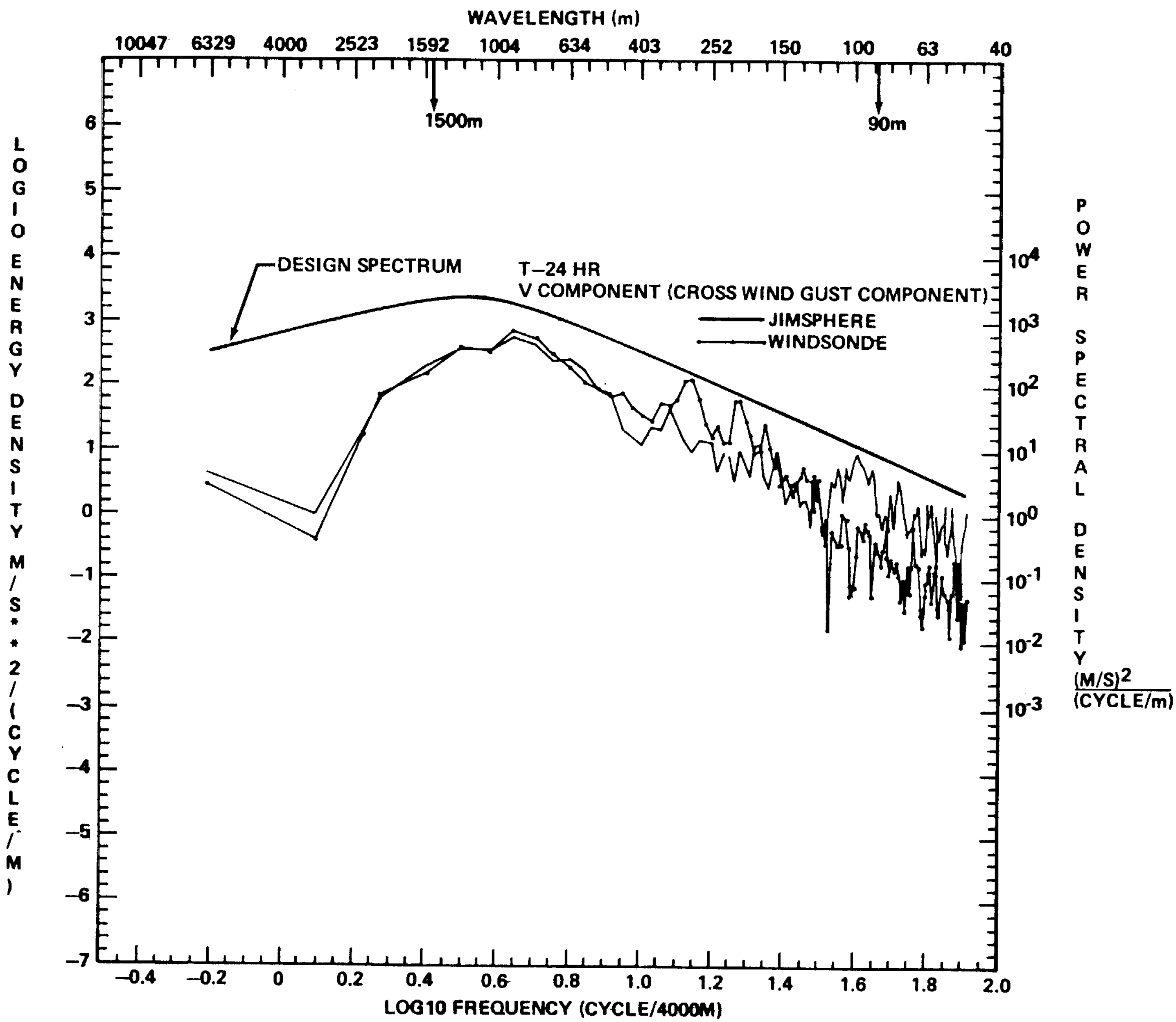

Figure 50. T-24 hr spectra of V component of Jimsphere (1829Z, November 25, 1985) and Windsonde (1826Z, November 25, 1985) for launch of STS on November 26, 1985 (1829Z) at KSC.

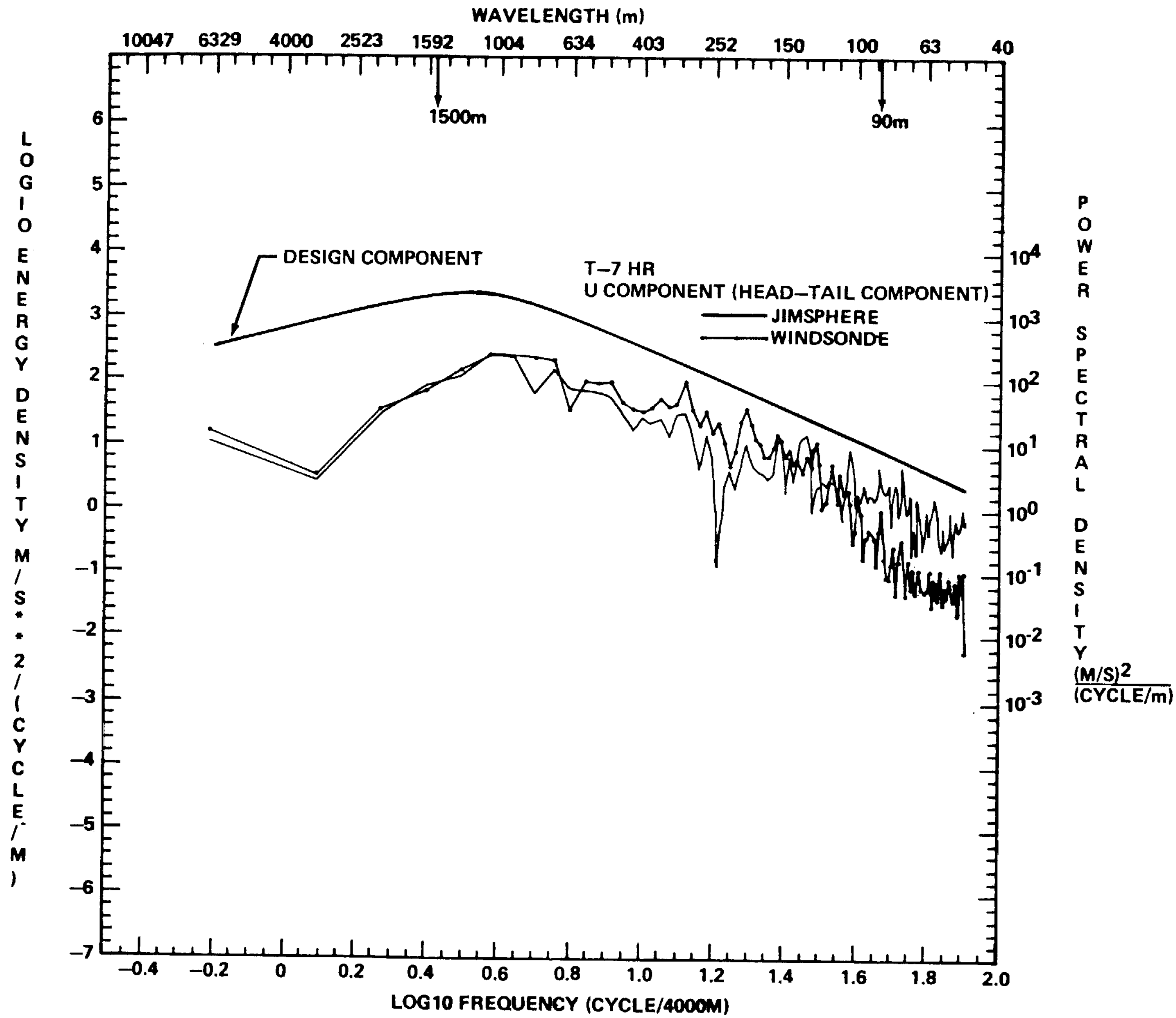

Figure 51. T-7 hr spectra of U component of Jimsphere (1129Z, November 26, 1985) and Windsonde (1120Z, November 26, 1985) for STS launch on November 26, 1985 (1829Z) at KSC.

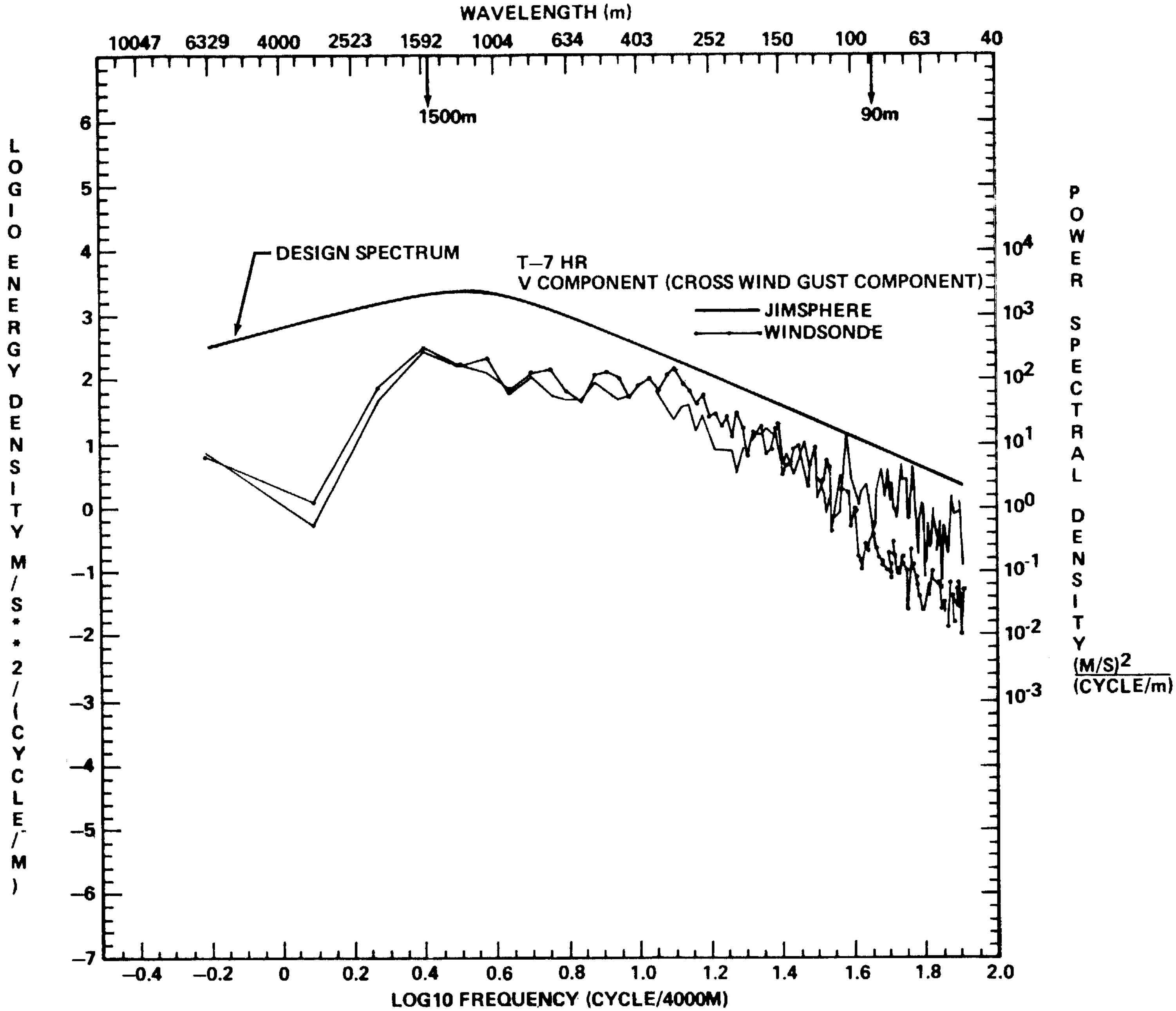

Figure 52. T-7 hr spectra of V component of Jimsphere (1129Z, November 26, 1985) and Windsonde (1120Z, November 26, 1985) for STS launch on November 26, 1985 (1829Z) at KSC.

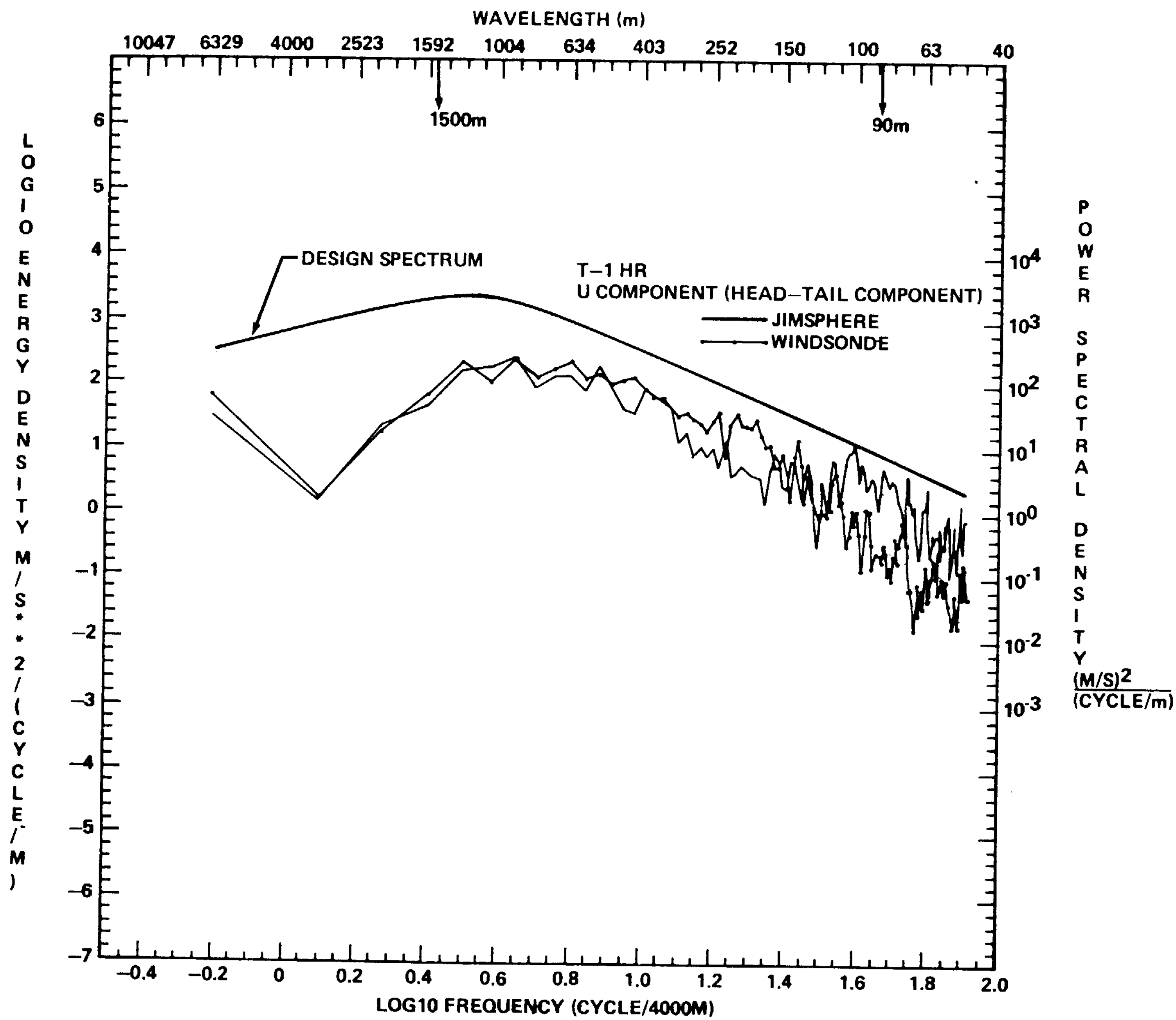

Figure 53. T-1 hr spectra of U component of Jimsphere (1714Z, November 26, 1985) and Windsonde (1728Z, November 26, 1985) for STS launch on November 26, 1985 (1829Z).

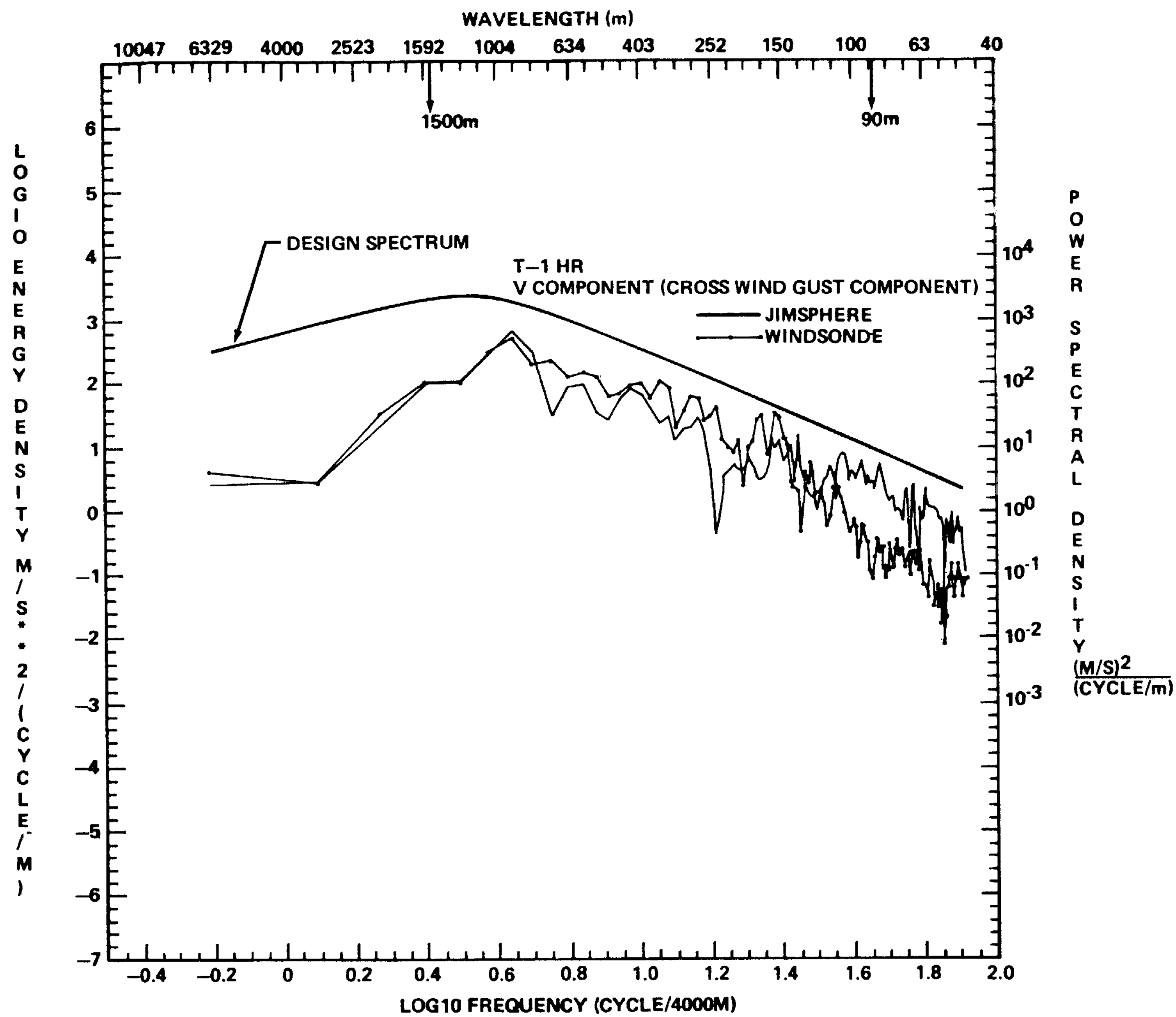

Figure 54. T-1 hr spectra of V component of Jimsphere (1714Z, November 26, 1985) and Windsonde (1728Z, November 26, 1985) for STS launch on November 26, 1985 (1829Z) at KSC.

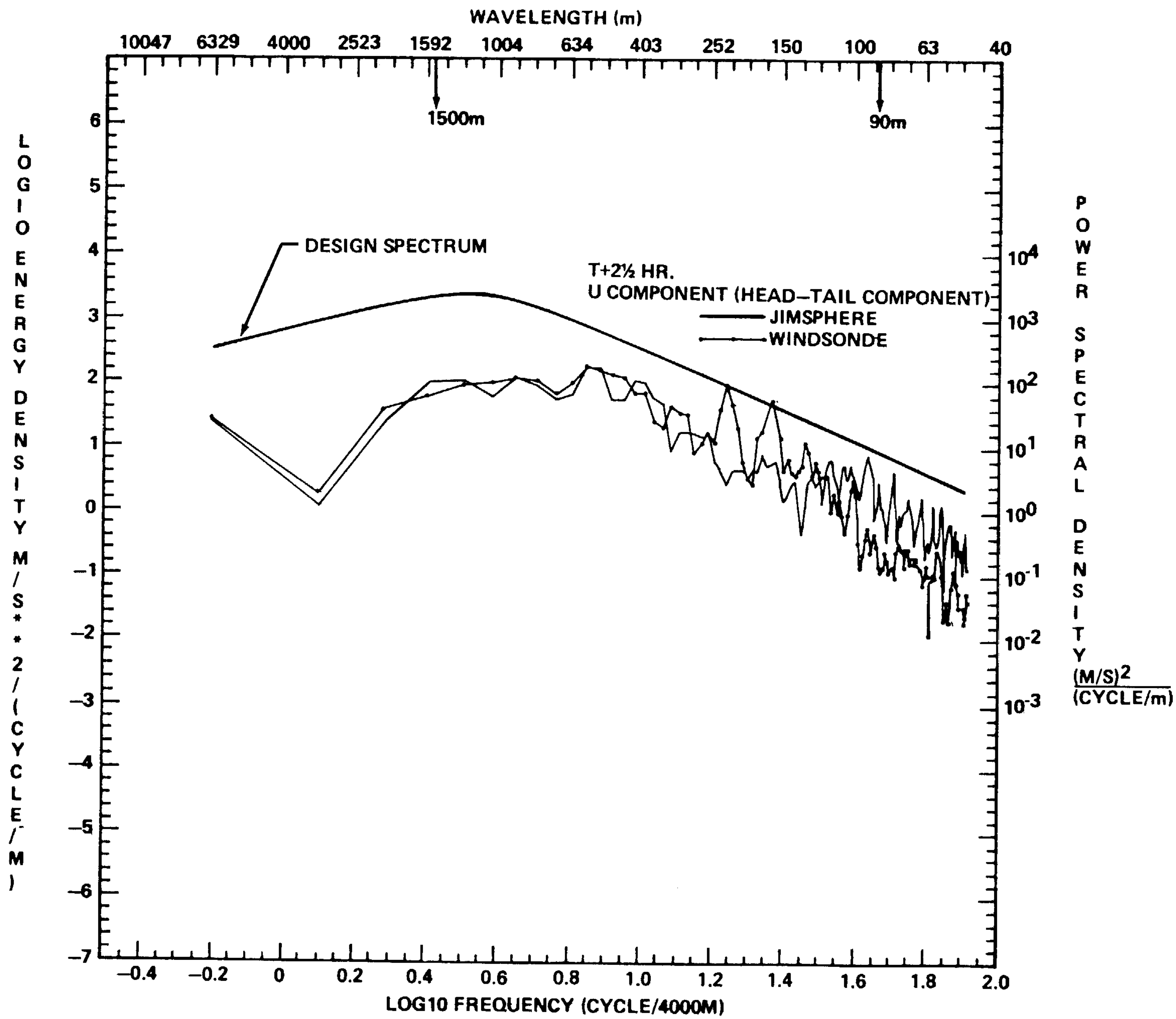

Figure 55. T + 2.5 hr spectra of U component of Jimsphere (2059Z, November 26, 1985) and Windsonde (2053Z, November 26, 1985) for STS launch on November 26, 1985 (1829Z) at KSC.

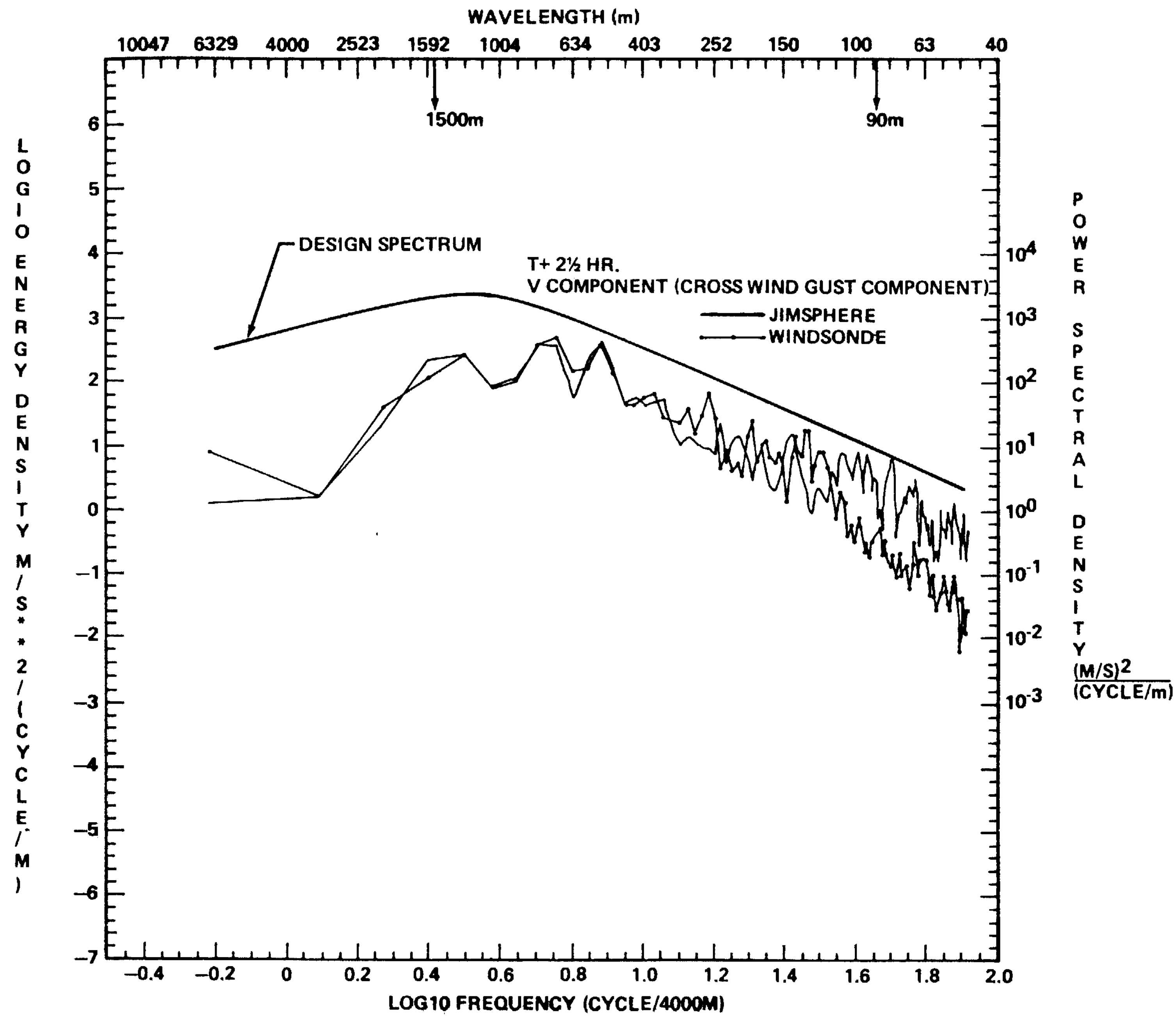

Figure 56. T + 2.5 hr spectra of V component of Jimsphere (2059Z, November 26, 1985) and Windsonde (2053Z, November 26, 1985) for STS launch on November 26, 1985 (1829Z) at KSC.

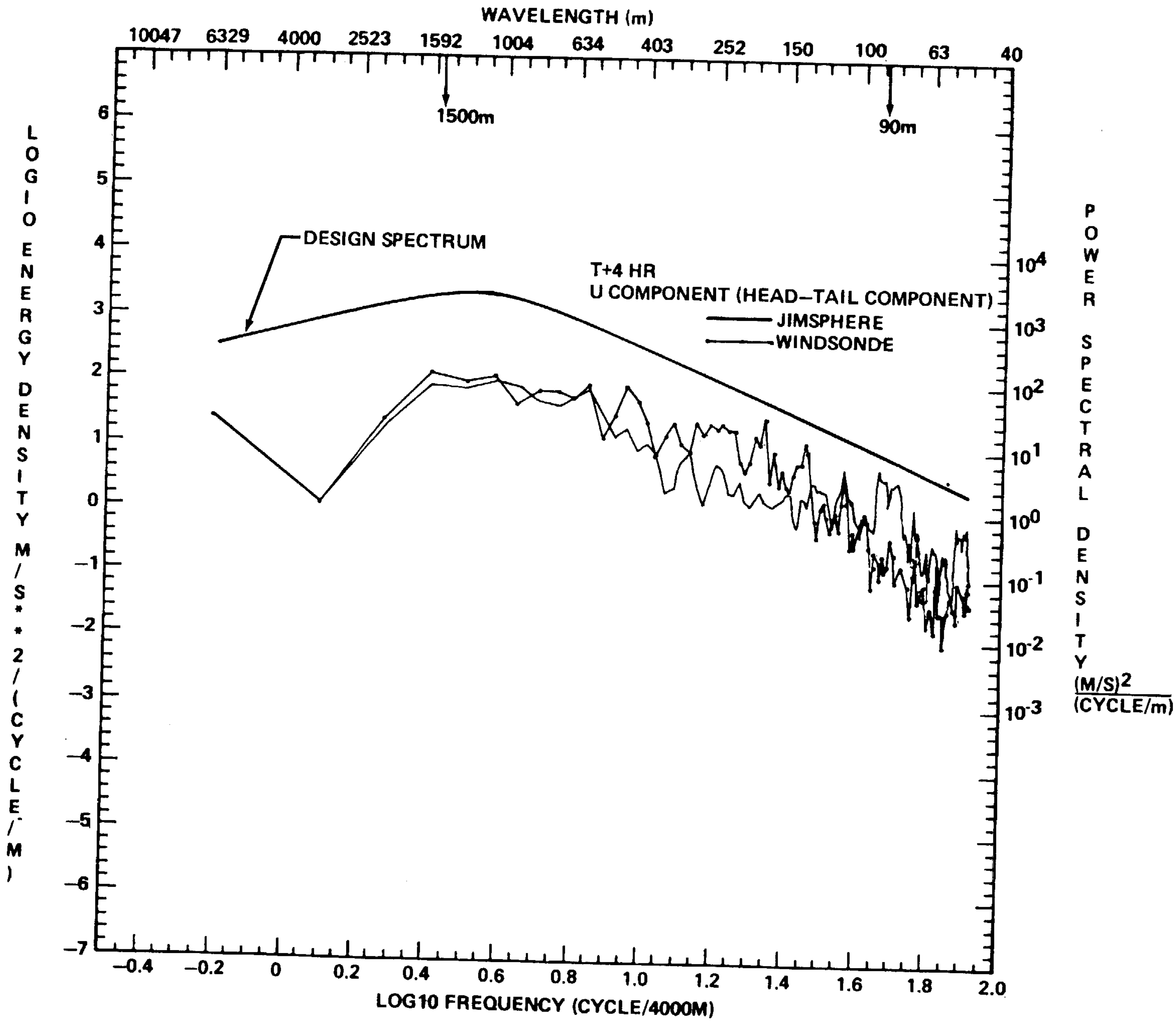

Figure 57. T+4 hr spectra of U component of Jimsphere (2214Z, November 26, 1985) and Windsonde (2229Z, November 26, 1985) for STS launch on November 26, 1985 (1829Z) at KSC.

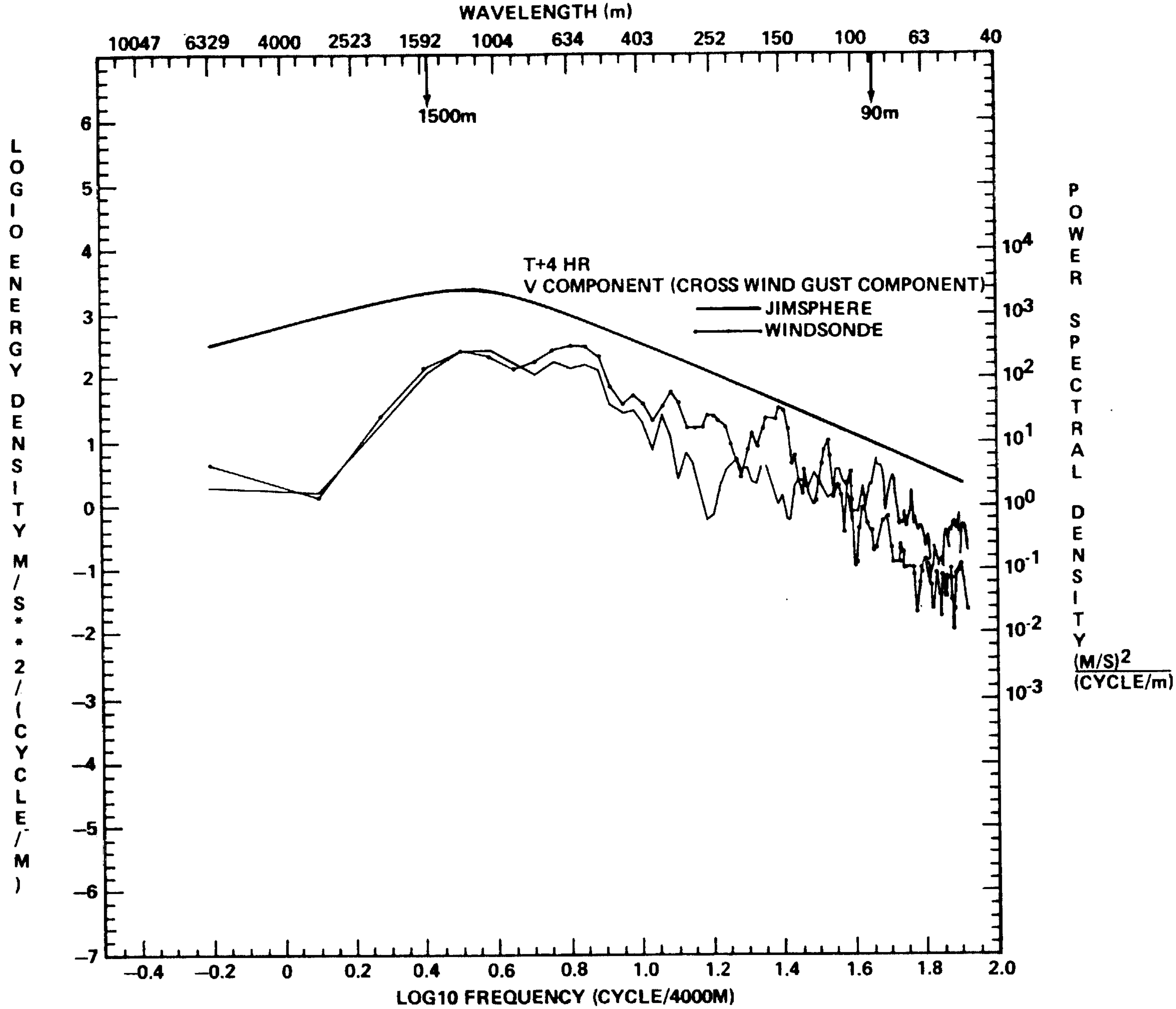

Figure 58. Spectra of V component of Jimsphere (2214Z, November 26, 1985) and Windsonde (2229Z, November 26, 1985) for STS launch on November 26, 1985 (1829Z) at KSC.

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16. ABSTRACT

The purpose of this report is to present an analysis of the bivariate parameter differences between the FPS-16 Radar/Jimsphere and the Meteorological Sounding System (MSS) Windsonde. The Jimsphere is used as the standard to measure the ascent wind loads during the Space Shuttle launches at Kennedy Space Center, Florida, and the Windsonde is the backup system. In addition, in the report a discussion of the terrestrial environment (below 20 km) and a description of the Jimsphere and Windsonde wind sensors are given. Computation of the wind statistics from 64 paired Jimsphere and Windsonde balloon releases in support of 14 Space Shuttle launches shows good agreement between the two wind sensors.

The computed difference values in m/s of the mean zonal wind ($\overline{u}$) and mean meridional wind ($\overline{v}$) of the Jimsphere and Windsonde at 500 m intervals from the surface to 16 km shows good agreement between the wind components. The ($\overline{u}$) and ($\overline{v}$) mean differences for the 64 paired observations were 0.16 and 0.22 m/s respectively, while the standard deviations of the mean differences of $\overline{u}$ and $\overline{v}$ were 1.38 and 1.73 m/s, respectively.

From the analysis of the buildup and back-off data for various scales of distance and the comparison of the cumulative percent frequency (CPF) versus wind speed change, it is shown that the wind speed change for various scales of distances (m) 100, 200, 400, 600, 800, 1000, 2000, 3000, and 5000 for the Jimsphere and Windsonde compare favorably. For example, the average altitude, where the greatest buildup occurred for all the scales of distances was at 10,427 m for the Jimsphere, 10,529 m for the Windsonde, and 10,474 m for the Jimsphere/Windsonde pairs,a range of only 102 m. The S.D. of these parameters were 2999, 3029, and 3007 m, less than a 50 m difference.

The variance difference of energy for the Power Spectral Density parameters for the u and v components of the Jimsphere and Windsonde was less than $\pm$ 0.02 m^2/sec^2. This showed very good agreement between the Jimsphere Wind sensor and its backup, the Windsonde in the all-important variance parameter, the energy difference between the Jimsphere and Windsonde at various wavenumbers or wavelengths.

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